CHAPTER 2
REVIEW OF LITERATURE

2.1. WHEAT GRAIN CHARACTERISTICS

The wheat grain is a caryopsis, i.e. a single seeded fruit in which the ripened ovary wall is fused with or closely connected to the seed. During caryopsis development, pigments accumulate in the persisting inner integument, which later becomes part of the ripe seed coat. Ripe wheat grains vary from light yellow to red-brown according to the absence or presence of red pigmentation in this layer. The amber color of some T. durum wheat is the result of pigments in the endosperm showing through clear seed coats. Color is controlled by three separate genetic loci, and thus depth of color can vary among the cultivars (Freed et al., 1976). The purple color found in some Ethiopian wheat was introduced into a common wheat cultivar, which created interest as a source of exotically colored whole-wheat products (Anonymous, 1986). Wellington (1956) suggested that white wheat permits water entry more rapidly than red wheat and in consequence are more susceptible to sprouting. However, King (1984), using isogenic lines differing in grain color, found no consistent relationship between color and water penetration or germination.

2.1.1. Grain Texture

The structure of wheat grain is important for all aspects of utilization, as it determines the grain’s behavior during processing. Kernel hardness along with its moisture content plays a significant role with regard to quality and suitability of grinding certain wheat in the mill. The weight of thousand kernels, determined from whole sound kernels by removing all foreign material and broken kernels provides millers with the milling potential of wheat. Endosperm texture is a key determinant of processing quality as it affects milling behavior. During milling, the grain is mechanically separated into various components on the basis of how it is composed structurally. Variation in grain hardness, which is a structural as well
as a biochemical feature, affects the flour yield, amount of starch damage, and energy requirements as well as many other factors (Hlynka, 1964; Pomeranz, 1971). Texture of the endosperm also affects the perception of grain color. Like pigmentation, it is a stable varietal characteristic, but it is also subject to a degree of variation according to growing conditions or weather conditions during ripening (Symes, 1965). The absence of air spaces in the endosperm of hard wheat gives the continuous tissue a glassy appearance. Soft, chalky endosperm increases the paleness of white wheat and diminishes the color of red wheats. The reverse is true for hard, vitreous wheats. Vitreous grains have a higher true specific gravity than mealy grains (Bailey, 1916). The difference in texture in general, reflects the number of microscopic air cavities within the protein matrix of the endosperm cell contents, with floury endosperm being characterized by such discontinuities. Vitreous bread wheat as well as durum wheat usually have no cavities and therefore have a vitreous appearance. It is one of the wheat quality parameters highly correlated with flour yield. A major locus (Hardness, Ha) located on chromosome 5D is the major determinant of grain hardness or softness (Law et al., 1978). Minor loci contributing to texture have also been mapped (Turner et al., 2004, Wilkinson et al., 2008). Softness has been related to the presence of proteins in fractions extracted from the surface of starch granules. A band of about 15 kDa by SDS-PAGE was present in large, small and zero amounts on starch granules from soft, hard, and durum wheats, respectively (Schofield & Greenwell, 1987). It was termed as ‘friabilin’ because of its close correlation with soft endosperm, and was linked to the Ha locus (Greenwell & Schofield, 1989).

2.1.2. Effects of environment

The effects of environmental and genetic factors on wheat flour quality have been studied extensively (Lukow & McVetty, 1991, Huebner et al., 1977, Ames et al., 1999). The effects of environmental conditions on starch structure and properties have been studied in terms of yields, planting date, growth temperature, day-length (diurnal), type of illumination, illumination intensity,
rainfall, carbon dioxide concentration and soil composition; with growth temperature being the most extensively studied parameter (Tester & Karkalas, 2001). Finney (1954) found that wheat harvested 10 to 14 days before maturity showed optimum loaf potential and good crumb structure. The dough mixing requirement and mixing tolerance of flour were also generally superior to those of dough from wheat harvested at maturity. The maximum loaf volume potential was related to the time that the storage protein bodies fused to form the protein matrix present in the mature wheat endosperm (Bechtel et al., 1982). Wheat amyllopectin chain distribution responds differently to increasing growth temperature compared to rice and maize starch where chains of DP 10-16 tend to increase but those with DP 17-21 decrease (Shi et al., 1994). Several proteomic studies of wheat grain development have been reported, comparing the patterns at different developmental stages and the impact of environmental factors on them. Skylas et al., (2002) and Majoul et al., (2004) focused on the effects of heat stress on the wheat proteome comparing heat-tolerant and heat-susceptible cultivars, and analyzing developing (17 DAA) endosperms grown at day temperatures of 24 and 40°C. The heat-tolerant cultivar revealed a stronger response to heat, and a total of 48 differentially expressed spots were characterized by mass spectrometry. Similarly, Majoul et al., (2004) identified 43 proteins that were differentially expressed in mature grain when the cultivar was grown at 18 and 34 °C during the day. Singh et al. (2008) studied the effect of water stress (WS) at 8 and 15 days post anthesis (DPA) on the characteristics of starch and protein separated from different wheat varieties. WS-induced changes in starch granules distribution were observed and were variety as well as stage-dependent. A-granules increased in response to water stress at both stages, the extent of increase being greater at 15 DPA. The proportion of B- and C-granules decreased in all the varieties. The starch from wheat exposed to WS at 15 DPA showed lower amylose content, lipids content and pasting temperature, and higher peak viscosity, final viscosity and setback. Transition temperatures ($T_o$, $T_p$ and $T_c$) of amylose-lipid complex dissociation and association were lower for starch from wheat exposed to WS, the effect being more at 15 DPA. The changes in pasting and thermal properties of
starch caused by WS were observed to be related to lipids, amyllose content and distribution of granules. The effect of WS on accumulation of different dimethyl formamide-soluble and insoluble proteins was significant and variety dependent.

2.2. WHEAT PROTEIN CHARACTERISTICS

Wheat proteins were first to be studied with Beccari (1745) reporting the isolation of wheat gluten. However, Osborne was the first to classify wheat grain proteins on the basis of their solubility: albumins (soluble in water), globulins (salt), gliadins (aqueous alcohol) and glutenins (dilute acid or alkali) (Osborne, 1907). Osborne classification groups consist of complex heterogeneous mixtures of proteins with some overlap between classes, the methods of protein fractionation have been improved thereafter (MacRitchie et al., 1990). The currently used protein classifying system is based on biological characteristics of the proteins together with their chemical and genetic relationship, leading to different states of aggregation in dissociating solutions (Shewry et al., 1986; Shewry & Tatham, 1990). The terms prolams and glutenins are generic terms applicable to all protein fractions extracted similarly from cereals whereas the terms gliadin and glutenin describe these two groups specifically present in wheat. Gluten, which constitutes the major storage protein fraction of wheat flour, can be further fractionated with aqueous alcohols into the soluble, predominantly monomeric gliadins and the insoluble aggregated glutenins (Sussane & Wieser, 2001). Gliadins are a mixture of monomeric polypeptides extractable in aqueous alcohol solutions (Schofield, 1994) and glutenins consist of polypeptides aggregated by disulphide bonds insoluble in aqueous alcohol solution and extractable in dilute acid or alkali (Shewry & Tatham, 1990; Singh & MacRitchie, 2001).

2.2.1. Gliadins

Gliadins in gluten or flour are present in a monomolecular form and have somewhat asymmetric compact structures that are stabilized by intra-molecular disulphide bonds. Viscosity measurements on gliadins indicate that the molecules,
although globular in nature, may not actually be spherical but rather may have more of an ellipsoid structure (Beckwith et al., 1966; Wu et al., 1967). More than 30 components are separated by two dimensional (2D) electrophoresis (Friedli, 1996). All gliadins are monomers with either no disulphide bonds (α-gliadins) or intra-chain disulphide bonds (α-, β-, and γ-gliadins) (Muller and Wieser, 1995, 1997). The molecular weights of α-gliadins are between 46 and 74 kDa and the α-, β- and γ-gliadins have lower molecular weight subunits, ranging from 30 to 45 kDa by SDS-PAGE and amino acid sequencing (Kasarda et al., 1987). The α- and β-gliadins are closely related and thereby they are often referred to as α-type gliadins. Most α-type gliadins contain six cysteine residues. Because of the monomeric character of α-type gliadins, and the absence of free sulphhydryl groups, it has been assumed that the cysteine residues are linked by three intra-molecular disulphide bonds (Kasarda et al., 1987). The γ-type gliadins are single monomeric proteins with intra-chain disulphide bonds and are considered to be the ancestral type of the S-rich prolamins (Shewry et al., 1986). Complete amino acid sequences of several γ-gliadins have been deduced from genomic and DNA sequences (Okita et al., 1985; Scheets & Hedgcoth, 1988). Introduction of new protein separation techniques, such as two-dimensional electrophoresis and RPHPLC have made it possible to separate gliadins into many individual polypeptides and could resolve more than 30 separate gliadin polypeptides (Beitz, 1985).

2.2.2. Glutenins

The glutenin fraction is formed of a mixture of polymers, high-molecular weight glutenin subunits (HMW-GS) and low-molecular weight glutenin subunits (LMW-GS). The HMW-GS consists of non-repetitive domains of 88-104 and 42 residues at the N- and C-termini, respectively, separated by a longer repetitive domain (481-690 residues). These repetitive domains are responsible for molecular weight of the proteins (Eliasson & Tatham 2001). All HMW-GS are rich in glutamine (35 mole %), glycine (20 mole %) but lower in proline (10 mole
%) (Shewry & Tatham, 1997). Structure prediction indicates that the N- and C-terminal domains are predominantly $\alpha$-helical, while the repetitive domains are rich in $\beta$-turns. Many partial and full-length sequences of HMW-GS and LMW-GS have been determined (Shewry & Tatham, 1997). About 25 different HMW-GS have been identified in different wheat varieties (Payne & Lawrance, 1983; Lawrance, 1986). All the major HMW subunits of glutenins of which there are 3, 4 or 5 in any particular variety have now been sequenced. Collectively these account for about 1% of dry weight of the mature endosperm of the wheat grain (Payne et al., 1987). LMW-GS after reduction of disulphide bonds can be divided into two main groups; a major group of basic proteins with molecular weight of 42 to 51 kDa and a minor group with molecular weights of 30 to 40 kDa (Singh et al., 1991). LMW-GS are similar to $\alpha$- and $\gamma$-type gliadins both in molecular weight and in amino acid composition (Shewry et al., 1986). However, amino acid sequence (Tatham et al., 1990) and 2D-electrophoresis (Jackson et al., 1983) distinctly identify them from $\alpha$- and $\gamma$-type gliadins.

### 2.2.3. SDS-Unextractable polymeric proteins (UPP)

More recent studies have shown that gluten protein polymers have a wide range of size distribution, ranging from dimers to polymers with molecular weights up to millions (Larroque et al., 1996; Wrigley, 1996). The proteins with the highest molecular weight are reported to have the strongest correlation with strong dough properties (MacRitchie, 1984). A certain amount of these polymers remains unextractable in various extracting systems (acetic acid solution or SDS phosphate buffer). The % UPP (percentage unextractable polymeric protein in total polymeric protein) is often used as a measurement of the amount and size distribution of the polymeric protein (Field et al., 1983; Gupta et al., 1992). High % UPP values are related to a greater proportion of glutenin that is insoluble in SDS and for that reason are thought to be of the highest molecular weight (MacRitchie & Singh, 2004). Thus, wheat with a greater percentage of UPP is expected to have a greater dough resistance (elasticity) and a longer mixing
requirement than those with a greater proportion of extractable polymeric protein (Gupta et al., 1993).

2.2.4. Wheat gluten isolation

When wheat flour is mixed with water, the two native protein groups present, glutenin and gliadin, combine to form a viscoelastic mass called gluten. Wheat gluten, or vital gluten, is the concentrated protein prepared from wheat flour, usually by washing the starch from flour–water dough (MacRitchie, 1984). Freshly extracted gluten is a wet and gummy mass, which can be dried to form a free-flowing, light-tan colored powder containing 75–80% protein (Magnuson, 1985). Gluten is capable of forming adhesive and cohesive masses, films and three-dimensional networks, all essential to baking performance (Bloksma & Bushuk, 1988). Beccari (1745) was the first to describe the procedure for gluten isolation from wheat flour. Robertson et al., (1999) studied the separation of gluten from wheat using ethanol washing procedure and found that gluten swelling properties as a contributing factor to the success of the cold ethanol, gluten from starch separation process. The common way to prepare gluten from wheat flour dough is either by hand washing or by automatic gluten washing devices. According to MacRitchie (1984), the use of 200 ml of water per 100g flour and five separate washes can give gluten of about 70% protein content. Further washes produced higher-grade gluten, i.e. with higher protein content, but having a disadvantage of larger volumes of water that needed to be removed. Higher grades of gluten can be obtained with defatted flours than with whole flours, though it is usually difficult to achieve glutens with protein contents higher than 80% dry weight (MacRitchie, 1984). Following washing of gluten, the aqueous suspensions can be collected and centrifuged to produce water soluble fractions or starch fractions. Nierle et al. (1998) investigated the effect of remaining associated substances such as lipids and lipoproteins during extraction of wheat gluten and also reported that techniques such as magnetic stirring or soxhlet extraction with ethanol (45 and 90 cycles) for wheat starch separation did not cause any structure changes to wheat and gluten during separation. Roels et al.
(1998) studied a pilot-scale isolation of gluten from flour prepared from six European wheat varieties and recorded average gluten yields of 9.6%. They also observed gluten with good agglomeration properties and high level of glutenin during separation. Yondem et al. (2002) investigated the effect of water temperature, water to flour ratio on separation of bread wheat flour into starch and gluten fractions after dough making, maturation, dispersal of the dough in water during wet sieving/washing. Dik et al. (2002) also reported the combined effect of water to flour ratio, dough maturation time, flour aging, and ascorbic acid addition on the wet separation of gluten. They also reported that higher-grade wheat flour was found to have superior separation characteristics and yield higher quality gluten compared to the low-grade wheat flour samples.

The gluten proteins have been the subject of intensive studies for a period exceeding 250 years. This has revealed gluten proteins having unusual structures and properties, making them of special interest for studies as well as applied work about their functional properties (Shewry & Tatham, 2000). Many attempts to reveal the structure of the gluten proteins have been carried out, although they have been troubled by the low solubility and lack of crystallinity of the proteins. The solubility properties of gluten proteins are determined by the primary structures of the individual proteins and their interactions by non-covalent forces (notably hydrogen bonds and hydrophobic interactions) (Belton et al., 1998) and by covalent disulphide bonds (Shewry et al., 2002). Graveland et al. (1985) postulated a basic building block of three glutenin subunits linked through disulphide bond and a tetramer of this basic structure. These react with linear proteins having two or more reactive sulphhydryl sites to form a larger molecule called gluten II. Gluten I is a highly polymerized insoluble protein, which is thought to be the glutenin protein present in wheat flour. It is partially depolymerized during mixing and reforms during the resting stage of dough processing. Gao et al. (1992) examined the effect of small amounts of dithiothreitol (DTT) on dough consistency in farinograph and arrived at a slightly different model. They also postulated a subunit structure similar to Graveland's but specify both HMW and LMW subunits in their block.
2.2.5. Viscoelastic properties of dough and gluten

The viscoelastic behavior in the transition zone is relatively similar for all polymers, and is independent of polymer molecular weight and weight distribution (Ferry, 1970). Rheological properties of polymeric glutenins in wheat, with the multiple chain polymers in which the individual peptides or subunits are linked by disulphide bonds, have been shown to give more information about the relative size of the polymeric aggregates and their interactions (Tronsmo et al., 2002). Hydrated wheat gluten and wheat flour are described as viscoelastic materials, i.e. materials that exhibits both liquid-like and solid-like characteristics. Mixing flour with water, results in an even distribution of the ingredients and the development of a continuous gluten network (Indrani et al., 2003; Sandstedt et al., 1954). According to Bloksma & Bushuk (1988), mixing has three distinct functions in the development of the dough: distribution of materials, hydration, and energy input to develop a protein structure. Understanding the role of mixing energy is an essential step towards optimising wheat dough development (Schlentz et al., 2000). During the mixing process, dough is formed by a combination of shear and elongational deformations at high strain rates (MacRitchie, 1986). According to Jongen et al., (2003), a z-blade mixer provides a combination of rotational, shear and elongational deformations on the dough, which makes it difficult to understand dough mixing on a mechanistic level. It is therefore interesting to compare the effect of well-defined shear deformation with z-blade mixing on dough properties.

2.2.6. Empirical rheology

Farinograph is an empirical instrument, commonly used to evaluate the mechanical behavior of wheat flour doughs (Walker & Hazleton, 1996). Although these tests are destructive, imposing high deformations, they are useful because they reproduce process conditions rather well. Results are not given in terms of fundamental rheological properties. Thus, for studying dough rheology, researchers have also used basic rheometrical instruments, with well-defined geometries providing results in absolute physical units rather than in arbitrary
units. Schofield and Scott-Blair (1932) were the first researchers interested in testing the fundamental viscoelastic properties of dough systems. Due to the unique characteristics of wheat protein for forming dough with viscoelastic properties, the majority of studies on dough rheology concentrate on wheat flour dough (Bloksma, 1990; Szczesniak et al., 1983). Other studies focus on the rheology of wheat gluten, a constituent of wheat flour that is considered the main factor in the elasticity of wheat flour dough (Dreese et al., 1998). The effect of dough components is also significant for understanding dough rheological behavior. Starch (Szczesniak et al., 1983), lipids (Eliasson et al., 1981), gluten (Dubois, 1983) and water content (Slade et al., 1998) have all been considered extensively, and the effect of addition of starch from different plant sources to wheat flour dough has been a subject of interest (Zaidul et al., 2004). Mullen and Smith, (1965, 1968) by using the farinographic technique reported that the main difference between weak and strong flours was that the latter contained less acetic acid soluble proteins. The salt soluble fractions (albumins and globulins) of flour had little effect on mixing characteristics as observed by Farinograph. The protein-starch residue after extraction with acetic acid, increased in mixing requirements to optimum in the farinograph, whereas the water soluble gliadins markedly shortened the mixing requirements (Tanaka & Bushuk, 1976). The Farinograph is one of the most widely used recording dough mixers as reported by D' Appolonia and Kunerth (1984). A representative farinogram, with the commonly measured indices has been defined in ICC methods (1972). Dough development time (DDT) and stability time (ST) increase with the increasing strength of flour, whereas mixing tolerance index (MTI) and degree of softening (DS) decrease with increasing strength of flour. Stronger flours with higher protein content and better gluten quality are characterized by higher water absorptions (WA).

2.2.7. Fundamental Rheology

Several researchers (Campos et al., 1997; Lee et al., 2001; Schluentz et al., 2000) have studied the effects of either well defined shear or elongational
deformations and their combination (using a farinograph mixer) on dough properties. Lee et al., (2001) showed different effects of shear or extensional deformation versus their combination on dough properties. They concluded that pure shear or extensional deformation alone cannot produce a high quality dough (defined as a high fraction of protein matrix), comparable to that obtained by a farinograph mixer. Peighambardoust et al., (2005) compared the effect of simple shearing with z-blade mixing on physical properties of a highly aggregated fraction of gluten, glutenin macro polymer (GMP), at a relevant work input level. They found that, compared with mixing, both GMP wet weight and the size of the glutenin particles were stable upon simple shearing. The importance of the amount as well as composition of GMP in assessing wheat quality and predicting dough properties has been emphasized in many recent studies (Aussenac et al., 2001; Don et al., 2003; Moonen et al., 1986; Sapirstein & Suchy, 1999). Thus, the stability of GMP under simple shear conditions might lead to the formation of different structures in the dough compared to those normally seen in mixed doughs. According to Bloksma (1990), the macroscopic behavior of given dough, like that of any material, depends on its composition and microstructure (spatial arrangement of its constituents). It has also been reported (Letang et al., 1999) that the molecular structure of dough (i.e. type of bonds) directly affects its rheological properties. Dobrasczczyk and Morgenstern (2003) showed a correlation between the molecular structure of dough (presence or absence of long-chain branching in glutenin subunits) and large-deformation rheology. Numerous studies have confirmed that the rheological behavior of wheat flour dough at large deformations is dominated by the gluten fraction (Dobrasczczyk & Morgenstern, 2003; Kieffer et al., 1998; Sliwinski et al., 2004; Tronmo et al., 2003). Moreover, according to Tronmo et al. (2003), large-deformation rheological methods are better suited for characterizing flour doughs with respect to protein quality than small deformation methods (dynamic oscillatory testing and creep recovery). Thus, large-deformation rheology provides a basis to study structural changes in the protein phase of the dough microstructure, which has
been shown to account for its viscoelastic behavior and end-use quality (Bloksma, 1972; Faubion & Hoseney, 1990; Janssen et al., 1996).

2.2.8. Dynamic oscillation measurement

Adapted from techniques developed for measuring viscoelastic properties of polymer melts and concentrated solutions (Ferry, 1980; Barnes et al., 1989), dynamic oscillation measurement is one of the most popular and widely used fundamental rheological techniques for measuring cereal doughs and batters. These tests measure rheological properties (such as elastic and viscous moduli) by the application of sinusoidally oscillating stress or strain with time and measuring the resulting response (Dobraszczyk & Morgenstern, 2003). A mechanical spectrum, i.e. the frequency sweep of both moduli ($G'$ and $G''$) in dynamic oscillation can be used to distinguish between the elastic and viscous properties of material within the time. The viscoelastic behavior in the transition zone is relatively similar for all polymers, and is independent of polymer molecular weight and weight distribution (Ferry, 1970).

Rheological properties of polymeric glutenins in wheat, with the multiple chain polymers in which the individual peptides or subunits are linked by disulphide bonds, have been shown to give more information about the relative size of the polymeric aggregates and their interactions (Tronsmo et al., 2002). A great number of studies have shown that there are a lot of factors which influence rheological properties of dough and baking quality. Water content and flour type have a significant effect on storage modulus and phase angle ($\delta$) measured by an oscillatory test both in linear viscoelastic region and as a function of stress (Autio et al., 2001). Oscillatory measurements are known to be very sensitive to water content (Hibberd, 1970; Dreese et al., 1988; Navickis et al., 1982). Also changes in rheological properties of dough based on granule size distribution might be expected because an increase in the proportion of the small B-granules provides a much higher surface area for the binding of proteins (including amylases), lipids and water (Rahman et al., 2000). In a study of the effect of granule size on dough extension, it was found that small starch granules increase extensibility of the
dough, whereas large granules increase resistance to extension (Larsson & Eliasson, 1997).

2.3. WHEAT STARCH AND ITS CHARACTERISTICS

2.3.1. Fine Structure

Starch consists of two structural isomers, an essentially linear polysaccharide amylose poly (α,1,4-anhydroglucopyranose), and a highly branched polysaccharide amyllopectin (including α,1,4-linkages and α,1,6-branches) with the ratio of amylose and amyllopectin ranging between 25–28% and 72–75%, respectively (Manners, 1989; Sponsler, 1923). The extent of branching has been shown to increase with the molecular size of amylose (Greenwood & Thomson, 1959). Amylopectin is the major component with an average molecular weight of the order $10^7$ to $10^9$ (Aberle et al., 1994). Starch granules have a layered organization with alternating amorphous and semi-crystalline radial growth rings of 120–400 nm thickness emanating from the hilum. The amorphous rings consist of amylose and amyllopectin in a disordered conformation, whereas the semi-crystalline rings are formed by a lamellar structure of alternating crystalline and amorphous regions with a repeat distance of 9–11 nm (Cameron & Donald, 1992). The crystalline regions of the lamellae are mainly formed by double helices of amyllopectin side chains packed laterally into a crystalline lattice, whereas amorphous regions contain amylose and the amyllopectin branching points. Amylopectin clusters may contain amylose molecules that pass through both the crystalline and amorphous layers. These amylose molecules are proposed to be in a straightened conformation in crystalline regions and in a disordered conformation in amorphous regions (Kozlov et al., 2007; Matveev et al., 1998).

For starches, four types of supramolecular structures differing in macromolecular organization and characteristic sizes are well known. They are: crystalline and amorphous lamellae (~4–6 nm), amyllopectin clusters (~9 nm), semi-crystalline, and amorphous rings (~120–400 nm), as well as granules themselves (~0.5–100 μm) (Buleon et al., 1998; Imberty & Perez, 1988; Jenkins
& Donald, 1995; Kozlov et al, 2007). The ‘cluster’ model, which gives adequate description of the structure of amylopectin and normal starches, is generally accepted. Amylose and amylopectin are synthesized in wheat grains by biosynthetic activities of enzymes. The isoforms of granule-bound starch synthase (GBSS) are responsible for the biosynthesis of amylose fraction, whereas amylopectin synthesis is more complicated with concerted activities of the soluble starch synthase together with branching and de-branching enzymes (Ball et al., 1996). Small-angle X-ray scattering and neutron scattering have been shown to be useful for studying the arrangement of lamellar structures in semi-crystalline starch granules (Waigh et al., 1996). Noda et al. (2008) concluded that an increase in relative content of amylopectin chains with DP < 10 is accompanied by the correlated structural alterations manifested at all levels of starch granule organization (crystalline lamellae, amylopectin clusters, semi-crystalline growth rings, and granule morphology). Thus, the short amylopectin chains with DP < 10 were considered as an origin of the defectiveness in starch supramolecular structures.

2.3.2. Morphology

The size, shape and size distribution of granules are important distinguishing morphological features of starch from different botanical sources. Granule size has been reported to influence the functional and baking properties (Chiotelli & Le Meste, 2002; Liu et al., 2007; Park et al., 2004; Sahlstrom et al., 2003) and the pasting behaviour of starch (Ao & Jane, 2007; Shinde et al., 2003). However, variation in functional properties of starch is also likely to be due to the internal structure of the granules. Granule size is related to the molecular architecture of amylopectin and its molecular arrangement within the granule (Geera et al., 2006; Jane, 2006; Raeker et al., 1998). Starches from wheat (Triticum aestivum L.), barley, rye and triticale have a bimodal granule size distribution (Peng et al., 1999; Soulaka & Morrison, 1985; Stoddard, 1999). Specifically for wheat, there is one population of small spherical granules ranging in size from approximately 1–10 μm, which are referred to as B-granules, and
another population of larger lenticular-shaped granules ranging from about 15 to 40 μm, known as A-granules.

The A- and B-granules are considered to differ according to the time of biosynthesis during grain filling. Synthesis of A-granules begins four days after anthesis, with granule growth and development continuing over the next 20 days. Initiation of B-granule synthesis occurs 10 days after anthesis, with significant granule growth beginning 20 days after anthesis (Bechtel et al., 1990; Parker, 1985; Shinde et al., 2003). The temporal variation in the biosynthesis is considered to affect the size of the granules, and result in differences in the molecular organisation of the amylose and amylopectin fractions (Tester, 1997). According to Kulp (1972), the first starch granules are deposited in the endosperm cells of wheat are often kidney shaped and later develop into large, lenticular granules (A-granules). Stamberg (1939) calculated the average distribution of starch granules from 17 wheat starches using the data of Grew and Bailey (1927) and reported that by weight the proportions were 4.1% for small, 2.9% for intermediate and 93% for large granules.

Optical microscopy and scanning electron microscopy is predominantly used for looking at the whole granule. The examination of starch granules reveals pronounced concentric rings under optical or electron microscopy (French, 1984). Kassenback (1978) reported that at higher levels of organization, the semi crystalline rings are composed of stacks of alternating crystalline lamellae. The combined repeat distance of crystalline and amorphous lamellae accounts for the peak observed in small X-ray and neutron scattering experiments (Blanshard et al., 1984; Oostergetel & Van Bruggen, 1989). The currently accepted crystalline structure consists of radial arrangement of clusters of amylopectin.

Morphological characteristics of starches from different plant sources vary with the genotype and sowing practices. Svegmark and Hermansson (1993) reported that size and shape of starch granules might be due to the biological origin. Badanhuizen (1969) proposed that morphology of starch granules depend on the biochemistry of the chloroplast or amyloplast as well as the physiology of the plant. The granular structure of potato, corn, rice and wheat starches show
significant variation in size and shape when viewed by SEM. The average size of individual corn and wheat starch granules, range between 5-10 μm for small and 15-30 μm for large granules. The granules from wheat starch are spherical in shape. Potato starch granules have been observed to be oval and irregular or cubiodal in shape. The starch granules are angular shaped for corn, and pentagonal and angular shaped for rice. There have been reports of third class of very small C-type granules that are initiated at very late stage of grain filling (Bechtel et al., 1990). The small B-type starch granules have a particular impact on the processing quality of wheat (Stoddard, 1999).

The surface of wheat starch granule contains protein (Simmonds et al., 1973) and lipids as well (Morrison, 1987). These contaminants play a pivotal role in the hardness of wheat kernels and behavior of wheat doughs. Soft textured wheat kernels have been associated with the presence of small protein (friabilin) on the surface of its isolated starch granules (Schofield & Greenwell, 1987). The higher surface-to-volume ratio of the B-granules has been associated with a higher rate of water absorption than that of A-granules, affecting the mixing of the dough and the baking properties of final goods (Hoseney et al., 1971; Soulaka & Morrison, 1985; Bechtel et al., 1990). Physico-chemical properties like percent light transmittance, amylase content, swelling power and water binding capacity were significantly correlated with the average granule size of the starches separated from different plant sources (Zhou et al., 1998).

There are compositional differences between small and large wheat starch granules; small granules contain more lipids than large granules (Soulaka & Morrison, 1985; Raeker et al., 1998), while they generally have lower amylase contents (Peng et al., 1999). Furthermore, large barley (Tang et al., 2001) and wheat (Sahlstrom et al., 2003) starch granules show a larger proportion of long amyllopectin chains (DP 24–30) than their small counterparts. On a higher structural level, large granules of barley (Tang et al., 2001) and wheat (Ando et al., 2002) starches are more crystalline. According to Harmansson and Svegmark (1996), light microscope and confocal scanning laser microscopes can be used to obtain information about features such as distribution of granules, degrees of
swelling of granules, and general distribution of amylose rich and amylopectin rich phases. A- and B-granules, were characterized structurally and evaluated for their functional properties (Salman et al., 2009). The amylopectin chain length distribution revealed that A-granules had a lower proportion of short chains with degree of polymerization (DP) 6-12 and a higher proportion of chains with DP 25-36 than B-granules. Salman et al. (2009), observed that A- and B-granules differed in structure and functionality, and that some correlations between their properties could be masked in un-fractionated starches with bimodal granule size distribution.

2.3.3. Physicochemical properties

Starch properties depend on the physical and chemical characteristics such as mean granule size, granule size distribution, amylose/amylopectin ratio and mineral content. The amylose content of the starch granule varies with the botanical source of the starch and is affected by climatic conditions and soil type during growth (Juliano et al., 1964; Morrison et al., 1984; Morrison & Azudin, 1987). The amylose content of the wheat starch varies from 18 to 30 % (Deatherage et al., 1955; Medcalf & Gilles, 1965; Soulaka & Morrison, 1985). Phosphorus is one of the non-carbohydrate constituents present in the starches, has been reported to significantly affect the functional properties of starches. Phosphatase is present as phosphate monoesters and phospholipids in starches. The phosphate monoesters affect starch paste clarity and viscosity while the presence of phospholipids results into opaque and lower viscosity pastes (Schoch, 1942a, b; Craig et al., 1989). Phospholipids present in starch have a tendency to form complex with amylose and long branched chains of amylopectin, which results in limited swelling. Wheat and rice starches have higher phospholipids content and produce starch pastes with lower transmittance as compared to the corn and potato starches with lower phospholipids content (Eliasson et al., 1981). More than 90% of the lipids inside wheat starch granules are lysophospholipids and have been thought to occur in the form of inclusion complexes with amylose (Morgan et al., 1993). Wheat starch lipids constitute 1% of the granular weight, having surface
lipids to the extent of 0.05% (Eliasson et al., 1981; Morrison, 1988). The lipids are present at lower levels and significantly affect the swelling of wheat starch (Morrison et al., 1993). It has also been reported that surface lipids oxidize and contribute to the so-called cereal odor of wheat starch.

Amylose forms crystalline complexes with a number of polar and non-polar compounds which, when characterized crystallographically, were found to exhibit the well defined V-amyllose structure. Complexing agents such as iodine, dimethyl-sulfoxide, lipids, alcohols, flavour compounds, etc. induce the formation of single, left-handed amyllose helices with a pitch of 0.805 nm, known as V-amyllose (Buleon et al., 1998). Amylose-lipid complexes are naturally present in starch and/or formed during gelatinization with endogeneous or added lipids (Morrison et al., 1993). Their importance is reflected in numerous food applications, such as the use of emulsifiers to retard bread staling (Riisom et al., 1984). Attempts to characterize the thermal behavior of amyllose-lipid complexes in aqueous environments have recently been made by using DSC. The amyllose-lipid complex melting point is detected by the presence of an endothermic transition at temperatures between 95 and 135 °C. Formation of the complex is thermo-reversible with a marked hysteresis (Biliaderis, 1985; Jovanovich, 1992; Bulpin, 1982), as evidenced by the presence of an exotherm in the cooling DSC curve.

Swelling power and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains. The extent of this interaction is influenced by the amyllose and amylopectin ratio, and by the characteristics of amyllose and amylopectin in the terms of molecular weight/distribution, degree and length of branching and conformation (Hoover, 2001). Since wheat, corn and rice starch granules contain lipids contrary to potato starch granules, this may possibly explain the difference in the swelling power of these starches. The differences in swelling power and solubility of starches from different sources may also be due to the difference in morphological structure of starch granules. Water binding and solubility of starch depend on damaged starch content. According to Hermansson and Svegmark (1996), corn and wheat
granules may swell up to thirty times their original volume and potato starch granules up to hundred times their original volume, without disintegration. It has been suggested that amylose plays a role in restricting initial swelling because this form of swelling proceeds more rapidly after amylose has been exuded. The increase in starch solubility, with the concomitant increase in suspension clarity is seen as mainly the result of the granule swelling permitting the exudation of amylose. The granules become increasingly susceptible to shear disintegration as they swell, and they release soluble material as they disintegrate. The hot starch paste is a mixture of swollen granules and granule fragments, together with colloidal and molecularly dispersed starch granules. The mixture of the swollen and fragmented granules depends on the botanical source of starch.

Pastes clarity varies considerably with the starch source, the amylose/amylopectin ratio, chemical or enzymatic modifications and addition of solutes. The starch granules swelling and the brittleness would affect the paste clarity (Craig et al., 1989). These authors classified the starches according to their paste (1% db) clarity as following: potato > Maize > waxy maize > amyloamaize. Works undertaken on the influence of solutes on starch paste clarity indicated variations of clarity according to solutes content and nature. Thus, sucrose and glucose increased considerably starch pastes clarity (Osman, 1984; Craig et al., 1989; Bello-Perez & Paredes-Lopez, 1996). As for lipids, they contributed to starch pastes opacity (Craig et al., 1989) contrary to the observations made previously (Bello-Perez et al., 1998) with stearic acid, palmitic acid. Addition of NaCl to starch paste did not present a well defined effect on clarity (Bello-Perez et al., 1996), whereas it reduced considerably transmittance and visual clarity but increased whiteness on potato starch paste (Craig et al., 1989). Moreover, phosphorylation generally increases starch paste transmittance at low degree of substitution but clarity decrease with the increase in the degree of substitution (Mahmoud et al., 2000). Starch media clarity would also be influenced by the macromolecular characteristics of amylose and amylopectin. Thus, clarity of reconstituted starch pastes (1% db) with amylopectin (80%) and amylose (20%)
from various origins decreased with the molar mass of amylose and the degree of polymerization of amylopectin (Jane & Chen, 1992).

2.3.4. Thermal Properties

The gelatinization of the native starch is required in almost all-culinary and industrial uses of starch (Blanshard, 1987). Gelatinization leads to a change in organization of the granule as a function of temperature and water content. The crystalline order in starch is often underlying factor influencing its functional properties. Atwell et al. (1988) reported that collapse of crystalline order within the starch granule manifests itself as irreversible changes in properties such as granule swelling, pasting, loss of birefringence and starch solubility. In an attempt to understand the precise structural changes underlying gelatinization, a number of techniques like differential scanning calorimetry, X-ray scattering, light scattering, optical microscopy, thermomechanical analysis (TMA) and NMR spectroscopy have been employed (Jenkins & Donald, 1998).

Many studies have been attempted to characterize the point at which birefringence is lost for a sample studied under an optical microscope. This point is termed as the birefringence end point temperature. The order disorder transitions that occur on heating an aqueous suspension of starch granules have been extensively investigated using DSC. DSC has been widely used to study thermal behavior of starches, including gelatinization, glass transition temperature and crystallization. Stevens and Elton (1971) first reported the application of DSC to measure the heat of gelatinization of starch. DSC has greatly expanded our understanding of phase transition in starch which starches undergo upon heating in presence of water (Ghiasi et al., 1982). The calorimeter uses small samples, which minimizes thermal lag within the system, and hermetically sealed pans, prevent loss of water. It also allows one to determine the temperature range over which gelatinization occurs and enthalpy involved in transition. Donovan (1979) reported that there are two endothermic peaks when heating wheat and potato starches with 27% water to 150 °C, and suggested that two kinds of structures or two different environments may be present.
Eliasson (1980) observed three peaks when a wheat/starch mixture with water content in the interval 35-80% was heated to 140 °C and concluded that DSC could not explain the second peak. DSC has also been used to study the glass transition temperature ($T_g$) of starch. Zelezank and Hoseney (1987) reported $T_g$ values of 50 to 85°C for wheat starch containing 55% water. Krüger et al. (1987) related starch transition temperatures with gelatinization enthalpies by DSC to characteristics of the starch granule, such as degree of crystallinity. Gelatinization occurs initially in the amorphous regions as opposed to crystalline regions of the granule, because hydrogen bonding is weakened in these areas. Gelatinization temperatures and enthalpies associated with gelatinization endotherms varied between the starches from different sources. In wheat starch, onset ($T_o$), peak ($T_p$) and final temperature ($T_c$) values have been found to range between 46.0 to 52.4 °C, 52.2 to 57.6 °C and 58.2 to 66.1 °C, respectively (Tester & Morrison, 1990). $T_p$ gives a measure of crystallinity quality (double helix region). Enthalpy ($\Delta H$) gives an over all measure of crystallinity (quality and quantity) and indicates the loss of molecular order with in the granule (Cooke & Gidley, 1992). $\Delta H_{gel}$ values for wheat and potato starches ranged between 14.8-17.9 J/g and 12.5-13.8 J/g, respectively. Amylopectin plays a major role in starch granule crystallinity; the presence of amylase lowers the melting point of crystalline regions and the energy for starting gelatinization (Flipse et al., 1996). According to Krüger et al., (1987) more energy is needed to initiate melting in the absence of amylase rich amorphous regions. This correlation indicates that the starch with higher amylase content has more amorphous regions and less crystallinity, lowering gelatinization characteristics (Eliasson & Karlsson, 1983; Soulaka & Morrison, 1985).

Compared with the A-type starch granules, B-type starch granules started gelatinization at a lower $T_o$ but had higher $T_p$ and $T_c$ (Seib, 1994). A-type starch granules had higher $\Delta H_{gel}$ value than B-type starch granule. Endothermic peak of starches after gelatinization and storage at 4 °C appears at lower transition temperatures. Longton and Legruys (1981) studied the crystallinity of wheat gels stored at 4, 21 and 30 °C using DSC and found that the crystallinity increased.
with time and occurred faster and to a greater extent as the storage temperature deceased. Water content was important factor for crystallization of starch gel and it did not occur when moisture content was below 20% or above 90%. Lee et al. (2001) observed gelatinization increased and retrogradation enthalpy after 96 hours of storage at 4 °C decreased with the increase in amylose content of wheat. The retrogradation enthalpy at the end of storage period drops down significantly. Recrystallization of amyllopectin branch chains has been reported to occur in less ordered manner in stored starch gels as it is present in native starches. This explains the behavior of amyllopectin retrogradation endotherms at a temperature below that for gelatinization (Ward et al., 1994). The variation in thermal properties of starches after gelatinization and during refrigerated storage may be attributed to the variation in amylose to amyllopectin ratio, size and shape of the granules and presence and absence of lipids.

2.3.5. Pasting Properties

Ceaser (1932) and Ceaser and Moore (1935) using a consistometer first recognized pasting characteristics of starch and starch containing products. The first Brabender Viscoamylograph became available in 1930s. It has become a standard equipment piece of equipment used by industry for characterization of starches and starch containing products. Anker and Geddes (1944) demonstrated the utility of amylograph in flour and starch technology. Traditionally these properties have been measured by the Brabender Visco/Amylograph, an instrument which requires a relatively large sample, and takes 45 minutes to 2 hours for each analysis, depending on whether only the peak viscosity is required, or whether the set back curve (obtained on cooling). Pasting characteristics were shown by Sandstedh and Abbott (1961) to be significantly affected by starch concentration. Mazurs et al., (1957) developed a graphical presentation of amylograph data to compare characteristics independent of starch concentration.

Rapid Visco Analyser (RVA) has been investigated as an alternative to the Brabender Viscoamylograph for determining noodle quality of wheat using starch samples and rice’s samples. A major advantage of RVA when used to measure
paste viscosities is the speed with which the procedure may be carried out. A rapid cycle of heating and cooling is probably more appropriate in mimicking processing methods than the longer heat-cool cycle used to assess pasting properties. Pasting characteristics of all-purpose flour measured by RVA were found to be similar to those measured by Brabender Viscoamylograph (Walker et al., 1988). Pannozzo and McCormick (1993) reported peak paste viscosity, measured using the RVA, was highly correlated with organoleptic eating quality of Japanese and Korean style white salted noodles. Oda et al., (1980) reported that the starch pasting properties had a profound effect had a profound effect on the eating quality of noodles. Kim et al., (2002) reported that RVA peak viscosity reported negative correlation with amylose concentration in starch. Positive correlations were observed for peak temperature, peak time and setback viscosity with amylose. The capability of easily programming the heating-cooling cycle gave a flexibility that permitted optimization of conditions to a particular use. It has been reported, however, that varying the heating and cooling conditions in RVA can lead to large changes in the measured viscosity (Batey & Curtin, 1996). In particular, changing the initial temperature or the heating rate usually resulted in significant variation in the peak and final viscosities. It is therefore considered probable that the choice of operating conditions could be important in using the RVA for predicting noodle quality of wheats. Silver nitrate has also been used to inhibit amylolytic activity during flour swelling volume tests of breeding lines to overcome the effects of sprout damage (Crosbie & Lambe, 1993) and in the RVA measurements on landraces of wheat (Bhattcharya & Corke, 1996).

According to Hermansson and Svegmark (1996), during gelatinization, the starch granules first swell like balloon, subsequently collapse and become folded and simultaneously amylose leaches out from inside the granule, A three dimensional network is formed by leached out amylose (Eliasson, 1985a; Tester & Morrison, 1990). The swelling behavior of starch is the property of its amylopectin content, and amylose acts both as a dilutant and inhibitor of swelling (Tester & Morrison, 1990). Starch exhibits unique viscosity behavior with the change of temperature, concentration and shear rate (Nurul et al., 1999). Starches
that are capable of swelling to a high degree are also less resistant to breakdown on cooking and hence exhibit viscosity decreases significantly after reaching the maximum value. The increase in viscosity during the cooling period indicated the tendency of various constituents present in hot paste to associate or retrograde as the temperature of the paste decreases.

Sabularse et al. (1992) reported that damaged starch was negatively correlated with peak viscosity. Wang and Wang (2001) suggested that the damaged starch content play a more important role than protein content in determining peak viscosity of starch. The properties of different starch suspensions have been intensively investigated. Schoch (1969) attributed the viscosity of gelatinized starch suspensions to the frictional dissipation of energy in the movement of the swollen starch granules relative to one another. Miller et al. (1973) correlated the viscosity increase during the heating of starch suspensions with the exudation of a filamentous network from the starch granules. Collison et al. (1960) suggested that the flocculation of swollen granules affect the rheology of gelatinized starch systems. Schutz (1971) postulated that secondary bond between the hydrodynamic units, either directly or through intermediate water molecules, cause non-newtonian behavior of cooked starches.

2.3.6. Dynamic Rheology

Dynamic rheometer allows the continuous assessment of dynamic moduli during temperature and frequency sweep testing of the starch suspensions. The storage dynamic modulus ($G'$) is a measure of the energy stored in the material and recovered from it per cycle while the loss modulus ($G''$) is a measure of the energy dissipated or lost per cycle of sinusoidal deformation (Ferry, 1980). The ratio of the energy lost to the energy stored for each cycle can be defined by $\tan \delta$, which is another parameter indicating the physical behavior of a system. The initial increase in $G'$ could be attributed to the degree of granular swelling to fill the entire available volume of the system (Eliasson, 1986) and intergranule contact might form a three-dimensional network of the swollen granules (Evans & Haisman, 1979; Wong & Lelievre, 1981). With further increase in temperature, $G'$
decreases indicating that the gel structure is destroyed during prolonged heating (Tsai et al., 1997). This destruction is due to the melting of the crystalline region remaining in the swollen starch granule, which deforms and loosens the particles (Eliasson, 1986).

The rheological properties of the different starches vary to a large extent with respect to the granular structure. Potato starches showed higher breakdown in $G'$ than corn, rice and wheat starches. The differences in the breakdown values of starches may be attributed to the granule rigidity, lipid content and peak $G'$ values. The corn, wheat and rice starches being rich in lipids showed lower breakdown values. Similarly, wheat and rice starches with large sized granules also showed higher storage, loss modulus and lower tan$\delta$. Amylose content is another factor, which significantly affects the rheological properties of the starch. Lii et al. (1996) reported the increase in $G'$ and $G''$ of rice starch with the increase in amylose content during temperature sweep testing.

2.3.7. Retrogradation Properties

The behavior of gelatinized starches on cooling and storage, generally termed as retrogradation, is of great interest since it profoundly affects quality, acceptability and shelf life of starch containing foods (Biliaderis, 1991). Starch molecules in pastes, gels and baked foods are known to associate on ageing, resulting in affects such as precipitation, gelation and changes in consistency and opacity. This is accompanied by gradual increase in rigidity and phase separation between polymer and solvent. The effects of retrogradation in starch based products can be desirable or undesirable. Starch retrogradation contributes to staling of bread and other starch based products (D’ Appolonia & Mrad, 1981; Kulp & Ponte, 1981; Seow & Thevamalar, 1988). Retrogradation is sometimes promoted to modify the structural, mechanical or organoleptic properties of certain starch based products where retrogradation results in hardening and reduced stickiness (Collona et al., 1992). The retrogradation studies can be carried out by textural, rheological and thermal techniques using dynamic rheometer, differential scanning calorimetry and Instron Universal Testing Machine.
Instrument texture profile analysis developed by Bourne et al. (1966) using Instron Universal Testing Machine, has been widely accepted to the study of starch retrogradation in actual food and model starch gel systems. McIver et al. (1968) firstly reported the use of DSC to study starch retrogradation. In case of retrograded starch, the value of $\Delta H$ provides a quantitative measure of the energy transformation that occurs during the melting of re-crystallized amylopectin as well as precise measurements of the transition temperatures of this endothermic event.

The starch fraction responsible for retrogradation is amylopectin (Eliasson, 1985b). Retrogradation of amylopectin involves a crystallization process of the outer branches (DP 14-18). The recrystallization of amylopectin is a slow process continuing over a period of several days and weeks. Due to limited dimensions of the chain, the stability of these crystallites is lower than of amylose crystallites. The recrystallized amylopectin melts in the temperature range of 40-100 °C while amylose crystallite melts at much higher temperatures (120-170 °C). For common starches containing both amylose and amylopectin, a composite gel network forms, consisting of swollen amylopectin-enriched granules filling an interpenetrating amylose gel matrix (Miles at al., 1985). The long term storage causes the amylopectin to recrystallize, increasing the rigidity of swollen granules, which, in turn, reinforces the continuous amylose phase.

The amylose content has been reported to be one of the influential factors on starch retrogradation (Baik et al., 1997; Fan & Marks, 1998). Whistler and Bemiller (1996) reported that a greater amount of amylose has been traditionally linked to greater retrogradation tendency in starches. Yamin et al. (1999) proposed that amylopectin and other intermediaty materials also play an important role in starch retrogradation during refrigerated storage. The intermediate materials with longer chains than amylopectin may also form longer double helices during reassociation under refrigerated storage conditions. Yuan et al. (1993) reported that retrogradation has been reported to be accelerated by the amylopectin with larger amylose chain length. Shi and Seib (1992) indicated the retrogradation of waxy starches was directly proportional to the mole of fraction
of branches with degree of polymerization (DP) 14-24, and inversely proportional to the mole fraction of branches with DP 6-9. X-ray scattering is another approach that has been extensively used. Wide angle-X-ray has revealed the packing within the crystals of the granules, enabling a detailed analysis of different polymorphs (Imberty & Perez, 1988; Wang et al., 1998). Using WAXS during gelatinization in water, together with small angle neutron scattering, it has been possible to probe the processes that occur at both the molecular and supra-molecular length scales (Donald, 2001).

2.4. BULGAR

Bulgur or Bulgur is an excellent food source due to its low cost, storability (long shelf-life), ease of preparation, and high nutritional value, which resists mould contamination and attack by insects and mite (Bayram, 2000). An important property is that the starch is gelatinized and the kernel is almost cooked. It is more stable than wheat in hot and humid environments. The major biological differences between wheat and bulgur are that wheat has respiration activity and enzymes are active in the kernel in contrast to bulgur (Bayram, et al., 1996).

2.4.1. Debranning

Debranning or pearling is a process in which the branny layers from grain are removed by friction or abrasion operations. Debranning prior to roller milling of sprouted wheat resulted into flour with lower alpha-amylase activity (Harelund, 2003; Sekhon et al., 1992) This step also results in simplification of the milling flow, and reduction in the capital investment (Mousia et al., 2004). In case of durum wheat, debranning prior to milling improved the yield and degree of refinement of the semolina. Debranned wheat can be used as an extender of rice to increase the nutritive value of the end-product. Debranning properties, such as time to pearl to a constant extraction weight, are used as an indication of grain texture quality (Edney et al., 2002).
2.4.2. Cooking of grain

The effect of the cooking time and temperature on the dimensions and crease of the wheat kernel was studied during bulgur production (Bayram, 2004a). Wheat was cooked at different temperatures ranging from 87-97 °C for 140 min. The change of the length, two widths, weight, volume and density for the wheat kernel were determined during the cooking operation. In addition, in order to determine the effect of cooking time and temperature, rates, activation energy, Q10 and z-values were determined. Negative percent change values and the rate constant for the length and density of the wheat kernel were obtained at different cooking temperature. The crease side width increased gradually at each cooking temperature between 6.95-68.05%. Cooking time also significantly affected the change of the crease side. The secondary width was affected significantly by the cooking temperature and time. The crease has important guarding property for the length and secondary width and it also guards the kernel for the secondary width against the internal force up to 97 °C. The volume of the kernel also increased during the cooking operation significantly and showed greater percent change in value than the weight due to high amount of swelling of the wheat kernel.

The changes in soaking water properties (pH, absorbance, soluble solids content, conductivity and color values) during soaking of soybean to produce soy-bulgur were studied (Bayram, 2004b). All the properties of soaking water were significantly affected by soaking time and temperature. Leaching of some nutritional compounds was also observed from soybean to the soaking water. The pH, conductivity and soluble solids content of the water increased with increase in temperature indicating leaching of the acidic compounds, minerals and total soluble compounds, respectively. Maximum absorbance (turbidity) was obtained at 50 °C soaking. Yellowness and yellowness index were increased as temperature was increased in contrast to a decrease in lightness. The author concluded that leaching and re-absorption of some nutritional compounds occurs simultaneously. Hence, the initial quantity of the soaking water should be adjusted to limit the loss of the nutritional compounds in the discharging water.
2.4.3. Drying

Drying is an important stage in the processing of bulgur. It may not only produce a desired reduction in the moisture content but may also significantly affect a number of other properties as flavor, color, texture, and nutrient retention. The effects of different drying methods on the physicochemical and sensory properties of bulgur were investigated (Hayta, 2002). Solar drying and microwave drying methods significantly affected the bulk density of bulgur samples. The yield was highest for the solar dried bulgur, followed by microwave-, tray-, and sun-dried bulgur samples, respectively. The drying method affected protein extractability, bulgur yield, as well as water and oil absorption values of bulgur. The lightness (L) value was found significantly higher for solar-, sun-, and microwave-dried bulgur samples compared to the tray-dried bulgur. The drying methods affected the redness (a) and yellowness (b) values of bulgur, however, had no significant effect on flavor, mouth feel, and appearance.

2.4.4. Other sources

Elgun et al. (1990) investigated various properties of bulgur prepared from corn. They studied the effects of the maturation stage (milk, yellow, or ripe) and cooking form (on the cob or shelled) of Narman sweet corn on some selected parameters obtained in the bulgur-making process, and the physical and chemical properties of corn bulgur were obtained. In addition to corn, bulgurs of acceptable quality have been prepared from triticale by boiling for 10 min and cooking for 3 min or cooking for 10 min at 15 lb/in2 and 120°C (Singh & Dodda, 1979).

Koksel et al. (1999) studied the effect of processing and cooking on the chemical composition of barley bulgur. Barley cultivars were processed into bulgur by pressure cooking or cooking at atmospheric pressure and the effect of processing on the levels of thiamine, riboflavin, minerals such as Fe, Cu, Zn, Mn, Ca, and Mg as well as the phytic acid and β-glucan was studied. Significant decrease in ash, riboflavin and thiamine contents during bulgur processing was observed. Neither the cooking methods nor the dehulling process significantly affected the Fe, Cu, Zn or Mg content, however, the P, Mn and Ca content of the
bulgur were significantly lower compared with the corresponding raw barley. In contrast, levels of β-glucan were significantly higher in processed bulgur than raw barley. Protein contents of the samples did not change significantly during bulgur processing. Bulgur processed from barley appeared to retain most of the nutritional value of raw barley and showed high levels of soluble dietary fiber.

The review of literature indicated that limited work has been carried out on the relationship between various properties of starch and proteins separated from different Indian wheat varieties.