2. REVIEW OF LITERATURE

2.1 Corn Germplasm

In order to identify the natural changeability of different plant and seed attributes, germplasm banks are considered to be the valuable resources (Sandhu et al. 2005). Different accessions from germplasm banks helps in identifying the functional and compositional variation among seeds of plants. Corn germplasm is the genetic material of plant that is used for different applications by researchers, scientists and engineers. International Board for Plant Genetic Resources (IBPGR) is an international unit that standardizes the knowledge related to plant genetic resources and expedite the interchange and accessibility of germplasm information to researchers, scientists and organizations (Panigrahi et al. 1998). Corn serves as a model plant for studying the hybrid potency, genome progression and certain other biological phenomenon by scientific commodities (Romay et al. 2013). The corn genome exhibits a high level of genetic diversity and is complex as compared to other model plant species (Fu and Dooner 2002). For the improvement of corn grain and feed utilization by ruminants, corn germplasm has been evaluated by researchers for variation in endosperm properties such as grain virtuousness, hardness and density as well as for the differences in starch degradability (Correa et al. 2002, Johnson et al. 2002; Taylor and Allen 2005). Ngonyamo-Majee et al. (2008) studied the effect of maturity stage and the type of corn germplasm on grain virtuousness and starch degradability and observed the highest and clearest influence of corn germplasm.

2.2 Corn Grain

Corn is one of the most valuable cereal grain crops and is monoecious with separate male and female inflorescences located on same stem of plant. Corn grain is composed of an endosperm, a germ and a pericarp (Watson 2003). The principal storage tissue of the grain is endosperm that composes up to 85 % of the grain weight. The pericarp is the outermost covering of the grain that constitutes about 5-6 %. Germ portion is main source of ash and oil which constitutes approximately 1.1 % of the grain weight (Watson 2003). Pericarp being characterized by high crude fiber content is the
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outermost covering along with seed coat that helps in preventing the fungi and bacteria to penetrate (Hoopen and Maiga 2012). Corn of different types includes dent corn, flint corn, floury corn, waxy corn, popcorn and sweetcorn (Knott et al. 1995), have varied proportion of floury (soft) and horny (hard) endosperm in their tissue structure (Kikuchi et al. 1982). The floury endosperm is softer and easier to break than the horny endosperm (Jamin and Flores 1998). The significant difference in horny to floury endosperm ratios among different corn types are caused by heritable and environmental circumstances (Hamilton et al. 1951). The central core surrounded by loosely packed starch granules constitutes floury endosperm, while tightly packed starch granules towards the periphery form horny endosperm (Singh et al. 2011a). The denting on crown of corn is due to shrinkage of floury endosperm during drying (Watson 1987). Flint corn has rounded crown with large amount of horny endosperm (Louis Alexander et al. 1991).

In India, the yellow flint corn is highly grown corn type, along with certain dent races that are also available in good quality. The availability of waxy and high amylose corn is limited but emphases are increased for production of such type of corn with high industrial value.

2.2.1 Color and composition of grain

The color of corn grains can vary from white to yellow, purple, blue, red-pigmented and orange (Watson 1987). The white and yellow color of corn endosperm is genetically controlled by certain genes (Zuber and Darrah 1987). The position of germ and color of corn cob adhering the grains are some physical factors responsible for variation in color of corn (Floyd et al. 1995). The color of corn grains has predominantly determined the antioxidant activity, anthocyanin, carotenoid and flavonoid content as well as phenolic compounds present in corn. The diversity in color of corn grains is due to certain pigments that can play a beneficial role in human health related to anti-mutagenesis and anti-cancerous activities (Adom and Liu 2002). Landi et al. (2008) made a diverse selection of corn on the basis of cob color and investigated the role of certain genes in controlling the grain color. Rodríguez et al. (2013) selected the corn grains with five different colors and studied a significant positive correlation of
antioxidant activity with color of grains that were separated visually. Lopez-Martinez et al. (2009); Hu and Xu (2011); Zilic et al. (2012) also reported that the dark color of corn grains is associated to higher pigment content that contributes to higher antioxidant activity. Betran et al. (2000); Giusti and Wrolstad (2003); Abdel-Aal et al. (2006) studied that anthocyanins are a class of flavonoids that contribute to red, blue and purple color of many fruits and cereal grains. de la Parra et al. (2007); Kuhnen et al. (2011) found that the yellow and orange color of corn endosperm is due to carotenes and xanthophyll pigments. Chandler et al. (2013) observed that yellow corn grains had high amount of carotenoids, while white corn grains had very less amount of these.

Nelson (1980); Soliman and Maksoud (2007) investigated the effect of moisture content on bulk density of corn grains. Wu and Bergquist (1991); Shandera et al. (1997) investigated the impact of test density, grain weight and proximate composition of grain on end product properties during milling processes of corn. Sandhu et al. (2007) studied the proximate composition of corn flour and reported that ash, fat, protein and carbohydrate content were ranged from 0.19 to 1.66 %, 1.56 to 2.42 %, 5.18 to 7.82 % and 87.6 to 92.5 %, respectively. A negative correlation of protein content with $L^*$ and positive correlation with $a^*$ and $b^*$ was recorded (Kaur et al. 2015). Zuber and Darrah (1987) reported the protein content of corn in the range between 9 and 11 % on dry weight basis. Houssou and Ayernor (2002) reported the percent reduction in protein, fat, ash and fiber content of corn flour caused by dehulling and degerming during flour preparation.

### 2.2.2 Mineral Composition

Corn has been reported to be the good source of trace elements that can help to combat the mineral deficiencies in human. Oikeh et al. (2003); (2004) studied the effect of genotype and environmental conditions on Zn and Fe content of corn grains and observed that both factors had a dominant effect on Fe and Zn concentrations along with the variety and location. Significant changes in Fe and Zn availability are a good contributor of these micronutrients to those relying on corn as primary source of daily diet. Menkir (2008) reported that Zn and Fe did not show any correlation with other mineral elements like P, K, Mg, Mn, Ca and Cu but had a significant positive
correlation with each other. The study of genetic variation in corn grain mineral elements other than Fe and Zn among different inbred lines is however, limited. The higher Ca and Fe content in improved yellow dent corn varieties than white dent corn varieties was recorded by Iken et al. (2002). Feil et al. (2005) studied the effect of variation in nitrogen supply and water regime on the concentration of various mineral elements and observed that the water did not affect the mineral concentration among corn varieties, while Nitrogen fertilizer reduced the concentration of Zn and Ca and increased the Mn concentration.

Gutiérrez et al. (2007) studied the Ca content in corn grains as a function of steeping time and temperature and observed that pericarp and germ were two major anatomical sources of Calcium. Naves et al. (2011) separately studied the mineral concentration of whole corn and germ plus pericarp portion and observed that germ and pericarp part had higher amount of minerals (Zn, Fe and Ca) as compared to whole grain. MacEvilly (2003) reported that the aleurone and pericarp layers of grain are major sources of minerals and vitamins and their final nutrient value is dependent on the degree of removal of these layers during processing. Belyea et al. (2006); Liu and Han (2011) compared the changes in concentrations of mineral elements with processing methods of corn. They concluded that dry ground corn showed the presence of K, Mg, Ca, Na, P, Cu, Fe, Zn, Mn and S. The dry milling of corn in different processing plants did not show variation in trace elements, whereas other processing streams like fermentation caused a significant increase in certain mineral elements when compared with ground dry corn.

Nascimento et al. (2014) studied the mineral composition of purple corn, amaranth and quinoa and observed that they all showed higher amounts of studied mineral elements when compared to rice. Ng’uni et al. (2016) observed the significant amounts of Fe, Zn, Cu, Mn and P in sorghum and indicated the possibility of genetic improvements for certain minerals like Fe in varieties with same genetic background, without altering the grain yield. McKeith (2004) reported that Fe, Mg and Zn were present in considerable amounts in whole grain cereals, along with certain lower levels of various trace elements.


2.2.3 Pasting properties of corn flour

The chemical components of corn grain and interactions among them are certain factors that control the pasting behavior of corn flour. Starch, fiber, proteins and lipids are the major constituents of corn flour that are contributing factors in the differences in pasting properties of flours (Houssou and Ayernor 2002). Zilic et al. (2011) reported the results which indicated that the quality and quantity of corn starch had more effect on pasting properties of corn than that of proteins. Also, the starch-lipid interactions played an effective role in gelatinization, pasting and cooling stage of paste viscosity. Zilic et al. (2011) investigated the pasting behavior of corn flour from different colored and types of corn and reported that yellow dent and semi-flint, white and red corn flour had the pasting graph with clear peak viscosity similar to that for typical normal corn flour, but the peak viscosity of flour from sweet corn was not detectable. The low paste viscosities for waxy corn flour are associated with very less amylose content and more amylopectin (highly branched) that prevent the close physical association between molecules (Bahnassey and Breene 1994).

Zhang et al. (2008); Liu et al. (2011) studied the effect of heat stress during grain filling on pasting properties of cereal flours and observed a significant decrease in pasting properties of wheat and rice flours and variations were more harsh during the early grain development than during the maturity. Lu et al. (2013) concluded that the trough, peak and final viscosities of waxy corn flours decreased due to heat stress during grain filling. The changes in physicochemical properties and starch structure of normal corn due to heat stress have been studied by Lu et al. (1996). The correlation of particle size of corn bran with pasting properties of corn flour was studied by Singh et al. (2013), with smaller corn bran particle size had the higher peak viscosity than that for larger particle size of bran. Hossen et al. (2011) studied the effect of pulverization on pasting behavior of flours from different sources and observed that the smaller size particles were more resistant to swelling.

2.2.4 Gel electrophoresis

The electrophoretic analysis of seed proteins and enzymes can be used for the laboratory varietal characterization of cereals and legumes. SDS-PAGE (Sodium
dodecyl sulphate-polyacrylamide gel electrophoresis) is a versatile technique to recognize and distinguish between different cultivars (or varieties) of particular crops. Several studies in identification of storage proteins of cereals including wheat (Zhao and Sharp 1996; Liu et al. 2010), barley (Basman et al. 2002; Hynek et al. 2006), rice (Tanaka et al. 1980) and sorghum (Shull et al. 1991) have been reported earlier for determination of the genetic diversity as well as end product quality.

The major seed storage proteins present in corn are prolamines, albumins, globulins and glutelins. Shewry and Tatham (1990) studied the structure of prolamine storage proteins in cereal grains. Prolamines are present in developing starch endosperm in protein bodies of cereals and are extracted from endosperm meal of corn. The presence of a repetitive peptide structure in polypeptide chains is the characteristic feature of prolamine molecules present in corn (Fukushima 1991). A huge diversification in nomenclature and isolation methods of corn storage proteins has been reported (Paulis and Wall 1977; Esen 1987; Wilson 1991). Zein is a major corn protein belonging to class of prolamines and present in endosperm, while albumins and globulins are mainly present in the germ portion (Shukla and Cheryan 2001). Singh et al. (2012) reported that whole corn grain contains about 39 % of zein and endosperm part has 47 % zein. Corn zein was differentiated as α-, β- and γ-zein based on the difference in molecular weight of polypeptide subunits (Esen 1986). Larkins et al. (1984) divided corn zein into four distinct classes where proteins with 19 and 24 kDa subunits were α-zeins; 14 kDa as β zeins; 16 and 27 kDa as γ-zeins and 10 kDa were reported as δ-zeins. Larkins et al. (1989); Dombrink-Kurtzman and Bietz (1993) studied the expression of zein genes during endosperm development and behavior of corn zein on the basis of endosperm type. The results of the study described that hard endosperm had more α-zeins and less amount of γ-zeins, while soft endosperm of same genotype showed the reverse trend. Moreover, the zein distribution throughout the grain of corn was reported to be non-uniform and protein composition was correlated to the texture of corn grain. Pavia et al. (1991); Landry et al. (2004) studied the distribution of 27 kDa γ-zein in soft and hard endosperm of grain from different types of corn and found the relationship of protein composition with grain hardness. Pratt et al. (1995); Robutti et al. (1997) also found a significant relation among zein classes, grain hardness and
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genetic background of corn lines. Pavia et al. (1991) reported the difference in α, β and γ-zeins among different corn varieties with quality protein maize (QPM) had higher level of γ-zeins and lower level of α and β zeins than that from normal corn varieties.

Corn glutelin subunits have disulfide linkage among several polypeptides in three dimensional structures (Landry and Moureaux 1981) and are distributed between the endosperm and the germ (Shukla and Cheryan 2001). Sadeghi and Shwarang (2006) studied the SDS-PAGE of corn flour protein subunits and identified that glutelins were composed of the subunits with molecular mass in the range from 25 to 50 kDa and prolamines were consisted of 22 and 24 kDa protein subunits. The albumins were labelled as smaller subunits of 10-20 kDa molecular mass in untreated and microwave treated corn proteins, while globulins were high molecular weight subunits of above 70 kDa. The degradation of albumin, globulin and glutelin subunits was recorded with incubation, whereas zein proteins were not degraded until 48 h.

A limited study on the role of zein proteins by using gel electrophoresis method in extrusion processing of corn has been reported. Robutti et al. (2002) analyzed zein proteins using RP-HPLC and suggested the role of zein for estimation of end use properties of corn extruded products. Batterman-azcona et al. (1999) reported that zein aggregation influence the sensory and textural properties of extruded corn products. Huynh et al. (1992) isolated a 22 kDa protein from corn and studied its antifungal effect on potato wilt and tomato early blight pathogens. Chen et al. (1998) isolated a 14 kDa protein from corn grains using SDS-PAGE along with some high molecular weight proteins and observed its role in trypsin inhibition homologous to that of 12 kDa protein isolated from Opaque-2 corn seeds by Swartz et al. (1977).

2.3 Antioxidant activity and phenolic content

The corn of different colors has received increased attention due to presence of certain pigments that plays a beneficial role in various aspects. Colored corn is a good source of several bioactive phytochemicals like flavonoids (Rice-Evans and Miller 1996), carotenoids (Lopez-Martinez et al. 2009), tocopherols (Ibrahim and Juvik 2009), phytic acid (de la Parra et al. 2007) and phenolic compounds (Santiago et al. 2007; Li et al. 2008). In spite of the non-nutritive nature, these compounds have potential health
benefits due to antioxidant and bioactive properties (Okarter and Liu 2010). The antioxidant properties and phenolic profiles are known to vary among the corn of varied phenotypic characteristics (de la Parra et al. 2007). The bound phenolics are associated with cell wall polysaccharides and are known to be effective against colon cancer (Shahidi 2009) and fulfill the nutritional requirements of human diet (Pandey et al. 2013). Pigmented corn (Zilic et al. 2012; Bacchetti et al. 2013) and waxy corn (Hu and Xu 2011) is a rich source of certain anthocyanins, carotenoids and phenolic compounds.

Hu and Xu (2011) determined the antioxidant activity of different corn varieties during maturation by 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay and observed significant differences among corn types. Zilic et al. (2012) studied antioxidant activity using DPPH reagent and total phenolic content using Folin–Ciocalteau (FC) reagent and reported the results with respect to the variation in color of corn grains. Adom and Liu (2002) reported that total phenolic content of corn was the highest when compared to that of wheat, oats and rice. Also, the high antioxidant activity of uncooked whole corn grains was reported. The variation in activity of antioxidants, polyphenols, flavonoids and anthocyanins in corn has also been studied by using different extraction solvents. Ramos-Escudero et al. (2012) used different concentrations of methanol and water to find the effect of extraction solvent on antioxidant and phenolics activity of purple corn varieties. Bonoli et al. (2004) studied the effect of using ethanol and acetone based extraction mixtures on extraction yield of free and bound phenolics from barley.

Phenolic acid and flavonoids are the most common types of phenolic compounds present in whole grains (Liu 2007). Sosulski et al. (1982) reported that vanillic acid, p-coumaric acid, ferulic acid, caffeic acid and syringic acid are the most common phenolics present in whole cereal grains. The phenolics like ferulic acid and caffeic acid were reported to be highly present in grains than in vegetables and fruits (Dewanto et al. 2002). Phenolics in corn grain are present either in soluble free or insoluble bound form attached to cell wall. The major proportions of phenolics present in corn grain are in bound form, whereas free phenolics contribute to 18-23 % of total phenolics in different phenotypes (Del Pozo-Insfran et al. 2006; Lopez-Martinez et al. 2009).
Ferulic acid is widely studied and important compound among all phenolics with potential health benefits (Renger and Steinhart 2000; Liu 2007). Ferulic acid occurs as an ester in aleurone layer of corn grain and attached to the cell wall polysaccharides (Lozovaya et al. 2000). Ferulic acid concentration in whole grains differs significantly among varieties. Cuevas Montilla et al. (2011) observed that ferulic acid was the most prominent compound in purple corn varieties. Kroon and Williamson (1999); Andreasen et al. (2001); Rondini et al. (2002) studied the polyphenols present in white corn and reported the anti-carcinogenic and antioxidant effect of ferulic acid and \( p \)-coumaric acid and their derivatives. Nishizawa et al. (1998) studied ferulic acid content in cereals and reported its relation with insoluble and total dietary fiber content. Srinivasan et al. (2007) reported the antioxidant property and free radical scavenging activity of ferulic acid which plays a beneficial role in human health. Pedreschi and Cisneros-Zevallos (2006) studied the antioxidant and anti-mutagenic properties of various phenolic fractions obtained from purple corn.

The concentration of different phenolics is highly dependent upon the type of variety, type of grain and the part of grain tested (Adom et al. 2003; 2005). The variation in concentration of phenolics in different fractions of corn grain has been studied. Bily et al. (2004) studied the bound phenolics from pericarp, embryo and endosperm fractions of corn grain and observed the highest proportion of bound phenolics in pericarp followed by embryo and the lowest in endosperm. Kennedy et al. (1999) identified sinapic acid, ferulic acid and \( p \)-coumaric acid in corn bran. Slavin (2003) reported that the whole grain consumption is helpful in preventing many diseases as they are rich sources of phenolics, antioxidants and minerals. Gallardo et al. (2006) reported the higher antioxidant activity of buckwheat and wheat germ products as compared to that of rye products. Zielinski and Kozlowska (2000) studied the total phenolics and antioxidant activity of whole grain, hull and pericarp extracts of buckwheat, ray, barley, wheat and oats.

The changes in phenolics concentration during processing have been reported earlier. Del Pozo-Insfran et al. (2007) studied the effect of processing (cooked grains, tortillas and chips) on polyphenols and antioxidants activity of white and blue Mexican corn genotypes, where the products made from blue Mexican corn showed higher
antioxidant capacity than those made from white corn. Also, acidification after nixtamalization helped in preventing antioxidant and phenolic losses. Dewanto et al. (2002) noted a substantial increase in total free phenolic content, total antioxidant activity, free ferulic acid content and decrease in bound ferulic acid during thermal processing of sweet corn as compared to that from raw sweet corn. Cortes et al. (2006) reported the effect of nixtamalization on stability of anthocyanins after separating germ, pericarp and tip cap from endosperm portion of blue corn.

Sharma et al. (2012) observed the effect of extrusion cooking of barley on phenolic and antioxidant activity and concluded that total phenolic content decreased while DPPH radical scavenging activity increased significantly up on extrusion. Morsy et al. (2015) reported the high antioxidant activity of rice based extrudates supplemented with Jew's mallow leaves. Masatcioglu et al. (2013) studied the antioxidant activity and total phenolic content of tomato, green tea and ginseng-supplemented corn extrudates and reported an increase in both with increase in extrusion temperature. Pandey et al. (2013) studied the phenolic compounds in different preparations of corn and their potential role in human health.

2.4 Corn Milling

Corn milling is an ancient practice used by human to obtain meal from corn grains. Each part of corn grain has its own benefits and uses (Griebat and Strief 2005). The corn is milled using different methods for fracturing the corn grain and obtaining different types of raw material for further processing or utilization. Shukla and Cheryan (2001) reported that corn processing is done by four different methods: Dry milling, wet milling, alkaline processing and dry grind process. Different milling procedures results into different type of end product. The dry milling and alkaline processed products are directly used for human consumption (Watson 1987). Wet milling method produce starch and oil, while dry grind method produces ethanol. Demand of corn type is different for milling industries with dry milling industry favors hard grains due to high product yield, while wet millers prefer soft grain to get better starch protein separation (Wu and Bergquist 1991).
2.4.1 Dry milling

Corn dry milling is a physical process to obtain the fractions of different particle size by removing the outer structures *i.e.* Germ, hull, pericarp and tip cap to get endosperm (Castells *et al.* 2008). The cleaned grains are tempered to equilibrate the moisture content for loosening the germ and pericarp from endosperm before milling (Rausch and Eckhoff 2016). Endosperm is the main component of dry milling which is further processed to produce various fractions like grits, flours, germ and meal (Alexander 1987). Grit and flour fractions are used as foodstuffs for human consumption, while germ is used for corn-oil production and pericarp is used for animal feed (Burger *et al.* 2013). Germ portion is characterized by high crude fat content (~33 %), high level of proteins (~18 %) and minerals (Zilic *et al.* 2011). High crude fiber content (87 %) consisted mainly of hemicellulose (~67 %), and cellulose (~23 %) and lignin (~1 %) is the composition of corn pericarp (Burger and Duensing 1989).

Different methods of corn milling have been proposed depending up on the product requirement. These include the grinding of whole grains to produce whole corn flour (Nago *et al.* 1997) and milling of dehulled grains to obtain flour (Mestres *et al.* 2003). On the other hand, initial dehulling and degerming of corn grains is done to obtain the grits that are finally ground to produce flour (Mestres *et al.* 2003). Velu *et al.* (2006) dried the corn grains in domestic microwave oven and studied the dry milling properties of corn. Corn grains are passed through counter-rotating roller pairs of varied roll gap, rolls corrugation and roll differentials for obtaining the fractions of varied particle size (Singh *et al.* 2009a). Scudamore and Patel (2009) differentiated the corn grit and flour on the basis of particle size for easy distinction of milling fractions products. The varietal differences in corn (Nago *et al.* 1997; Sandhu *et al.* 2007) and dry milling conditions (Martinez-Flores *et al.* 1998) highly influence the physicochemical and pasting characteristics of milled fractions. Corn grain density, grain hardness and test weight plays a wide role in defining the factors inducing the dry milling behavior (Kirleis and Stroshine 1990). Grit obtained from different corn types varies significantly in particle size, composition as well as end-use suitability (Singh *et al.* 2009a).
The selection of raw material possessing quality characteristics is a crucial classification step for corn dry milling industries in order to get more yields in relation to end-use products (Lee et al. 2007a). Grain size, grain weight, hard: soft endosperm ratios and grain density are certain characteristics that are highly related to the genotype along with growing and storage conditions of corn (Hill 1991). Eyherabide et al. (2004) studied the correlation of environmental sources and genotype with grain yield and endosperm hardness. Large flaking grits yield is highly dependent upon the grain density, grain weight and/or breakage susceptibility of corn grains (Paulsen and Hill 1985; Litchfield and Shove 1990). Peplinski et al. (1984) reported that dry milling quality is affected by type of varieties used and those with hard endosperm exhibit more desirable milling behavior due to low breakage susceptibility. Blandino et al. (2010) observed a positive relation of physical and chemical characteristics of grain, determining its hardness, with total grit yield obtained after dry milling. Gonzalez et al. (2004a) reported that the corn grits with hard endosperm would be beneficial for snack industry.

Mestres et al. (1991) reported that the dry milling behavior (semolina quality and quantity) could be determined on the basis of chemical compositions (protein and ash content) and physical features (sphericity/dent grain percentage) of different yellow dent corn hybrids. Housson and Ayernor (2002) studied the physicochemical properties of whole flour and dehulled-degermed flour of corn to determine the functional characteristics of products made from milled flours. A significant correlation of various physico-chemical parameters like ash and protein with grit and flour obtained from various reduction stages has been reported by Shevkani et al. (2014). The higher fat content of corn gives poor quality grit along with short shelf life of processed products (Hill 1991).

Almeida-Dominguez et al. (1997) obtained the rapid-visco-analyzer (RVA) curves of corn flour of varying particle size and found that the corn with hard endosperm had lower peak viscosities as compared to that of soft endosperm. Corn grit fractions obtained from dry milling showed a higher proportion of long chains of amyllopectin when compared to their counterpart flour fractions (Lin et al. 2001). A negative correlation of amylose: amyllopectin ratio with grain hardness associated
properties and protein content was observed that may indicate the formation of complex protein matrix causing an increase in grain hardness (Siska and Hurburgh 1994; Lee et al. 2005). Robutti et al. (2000) found a strong negative correlation of amylose content and endosperm hardness of corn grains which provide a compositional basis for endosperm quality. Prat et al. (1995); Mestres and Matencio (1996); Chandrashekar and Mazharb (1999) studied the role of different protein classes in corn grain hardness and concluded that the protein bodies with more γ-zein are associated with virtuousness.

Kirleis and Stroshine (1990) used thin layer dryer for drying dent yellow corn hybrids with varied drying temperature and time and then milled the samples and found a significant effect of drying temperature and hardness on milling quality of corn. Velu et al. (2006) studied the effect of microwave drying on dry milling of corn and observed less grinding energy consumption during milling. Walde et al. (2002) reported the similar effect of preprocessing conditions on properties of dough made from wheat flour.

2.4.2 Wet milling

The practice of separating starch from corn grains is known as wet milling of corn. The commercial method of isolating starch from corn grains involves the steeping of grains in an aqueous solution containing sulfur dioxide for about 48–50 h, that accelerate the separation of starch and gluten (Watson 1991). The corn processing by using wet milling method produces different end products including starch, oil, corn fiber (pericarp), germ meal (spent flakes), protein (gluten meal) and steep liquor (Hespell 1998). Ramirez et al. (2008) developed a process model for conventional wet milling of corn and reported the generated products yields as starch: 66 %, gluten feed: 19.4 %, gluten meal: 6.2 % and dry germ: 7.7 %. The basic steps in corn wet milling includes grinding of grains, screening, centrifugation, and washing to obtain starch, germ, fiber, and protein fractions (Wu 1996).

Starch is a chief constituent of plant foods and a principal raw material for industry (Mweta et al. 2008). Starch is the chief product of corn wet milling process (Blanchard 1992). The functionality of starches is highly influenced by botanical source, ecological conditions and varietal alterations (Srichuwong et al. 2005; Peroni et
Starch separation and purification is quite challenging as most of the starch is embedded in cytoplasmic matrix (Lorenz and Kulp 1980). The starch and proteins composition of corn is directly related to the grain hardness (Mestres and Matencio 1996). Corn grains with larger amount of floury endosperm than horny endosperm are more preferably selected for starch isolation because floury endosperm produces the starch which is higher in viscosity, easier to gelatinize, having more swelling value and α-amylase digestibility than that from horny endosperm (Kikuchi et al. 1982). Starch granules are principally comprised of linear amylose (α-1, 4-linkage) and branched amylopectin (α-1, 6-linkage) (Roger et al. 1999). In cereals and tubers, the starches contain an amylose content of 20 to 25 % (w/w). Amylopectin is a macromolecular structure with a crystalline region created by short linear side chains.

Wet milling of waxy corn is done to produce waxy starch which is utilized as a stabilizer by food industry and as an adhesive in the paper industry (Ptaszek et al. 2009). Cross-linking between amylose and amylopectin subunits provides the basis for the preparation of modified starches that are further used for thickening, stabilizing, and limiting retrogradation (Delville et al. 2002).

### 2.4.2.1 Amylose Content

The structure, composition, distribution and granular packing of amylose and amylopectin depend upon the origin of starches (Kurakake et al. 2009). Gao et al. (2014) reported that the variation in amylose content within the same botanical variety might be due to environmental and culture surroundings. Higher mobility and lower molecular size of amylose as compared to that of amylopectin is a distinct and important factor that determines the physicochemical characteristics of starch. Waxy corn is a starch variant of normal corn that comprised of ~100 % amylopectin, while normal corn is comprised of around 75 % amylopectin and 25 % of amylose (Sandhu and Singh 2007). Various technological as well as nutritional properties like gelation, pasting performance and enzyme hydrolysis are highly influenced by amylose content of the source (Whistler 1984). Perera et al. (2001) reported that amylose content of normal corn starch was 18.8 % and that of waxy starch was 0.0 %. Kuakpetoon and Wang (2007) examined the distribution of amylose and amylopectin in normal, high
amylose and waxy corn starches. Dombrink-Kurtzman and Knutson (1997) found that the corn with hard endosperm had the higher amount of amylose.

2.4.2.2 Starch granules size

Granule size is a distinctive characteristic of starch that varies in range from 1 to 100 µm in diameter with variation in size distributions (uni- and bi-modal) and forms (simple and compound), characteristic of their botanical origin (Tester et al. 2004). Corn starch (15 µm), potato starch (40 µm) and rice starch (5 µm) shows uni-modal size distribution, while wheat starch has bi-modal distribution (2-10 µm and 20-35 µm) (Jane et al. 1992). Singh et al. (2003) reported that potato starches had the largest granule size (110 µm) followed by wheat (30 µm), corn (25 µm) and rice (20 µm). The study of variation in particle size of starch granules is important as its characteristic role in estimating the mouthfeel as well as taste of fat substitutes (Daniel and Whistler 1990). Lim et al. (1992) studied the role of cereal starches in degradable plastic films with direct effect of particle size on film thickness and inverse effect on tensile strength. Puncha-arnon et al. (2008) reported that the granule size of two starches in a blend is the major factor influencing the gelatinization and pasting behavior of starches. Tran et al. (2011) reported that the grinding of cereal grains cause the distortion of granular structure and, hence, the damage to starch. Pan and Jane (2000) described the occurrence of elevated amount of amylose in large-size corn starch granules.

2.4.2.3 Pasting properties of starch

The pasting profile of starch signifies the variation in the viscosity of suspension in the course of heating and cooling under continuous stirring environment. RVA is widely used for determining the pasting behavior of starches from different sources. The pasting temperature quantifies the beginning of gelatinization. Uarrota et al. (2013) defined the pasting temperature as onset temperature in viscosity rise. Liu et al. (1997) reported that the starch from waxy corn showed lower pasting temperature that that from normal starches. The point of the highest swelling of starch granules gives the peak viscosity, with normal and waxy starches show the sharp peak and sugary starches give the smother peak (Li and Corke 1999; Perera et al. 2001). McPherson and Jane (1999) observed that the high peak viscosity of waxy starches is due to the negligible
amount of lipids, which upkeeps its rapid swelling. Larson (1980) reported that lipids and phospholipids are present in normal cereal starches that form the complexes with amylose and amylopectin and inhibits the starch swelling as well as the amylose leaching. On further increasing the temperature, starch gels undergoes shear thinning and viscosity calculated at this point is known as breakdown viscosity. Bahnassey and Breene (1994) reported that the waxy corn starch showed more breakdown viscosity as a result of the absence of amylose. With decrease in temperature to cooling, the gelatinized starch granules reassociate to some extent and form gel that cause an increase in viscosity, named as final viscosity.

The variations in amylopectin structure attribute to the differences in onset viscosity, peak viscosity, breakdown viscosity and pasting temperature during pasting and gel rigidity during storage (Doublier et al. 1987), while amylose composition contribute to the variation in final viscosity and setback viscosity (Vasanthan and Hoover 1992). Tziotis et al. (2005) reported that the amylose contents and amylopectin branch chain-length distributions chiefly affected the pasting properties of starch. The swelling of starch granules and the leaching out of the material from the granules collaboratively controlled the paste profile of starches (Eliasson 1986). The swelling behavior of starch is due to its amylopectin content, and amylose acts as both a diluent and an inhibitor of swelling (Tester and Morrison 1990).

Seetharaman et al. (2001) observed the substantial differences in pasting behavior of starches isolated from corn landraces in the Argentinean germplasm. Ji et al. (2003a) reported that the pasting performance of starches from different corn lines is influenced by the branch chain length pattern of amylopectin. Park et al. (2009) studied the mixing effect of potato and waxy corn starch on pasting properties and observed that the peak viscosity and pasting temperature varied and breakdown and setback remained unchanged with the variation in mixing ratios of both starches. Wang et al. (2000) studied the effect of addition of corn starch on pasting properties of rice flour and observed a decrease in paste profile due to presence of corn starch.
2.4.2.4 Thermal and Retrogradation properties of starch

Starch suspension is prepared by adding water, heating of which cause the swelling of starch granules those results into the changes in physicochemical properties of starch and the phenomenon is known as “gelatinization” (Greenwood and Thompson 1962). The unalterable changes occurring during starch gelatinization includes the swelling of granules, loss of birefringence, viscosity improvement, uncoiling of double helices and solubilization (Hoover 2001). During starch swelling, amorphous region undergoes expansion that causes the distortion of the crystalline region and these results into augmentation of the interaction of molecular chains of starch with water (Donovan 1979). Amylose present in starch granules leached out in water during heating and interacts with amylopectin chains of starch, which cause the formation of a threedimensional network (Tester and Morrison 1990). All these interactions during heating characterize the physicochemical properties of starches. Starch thickening and swelling are two desired operational characteristics of starches that depend upon the gelatinization behavior for their use in food industry as thickener (Karim et al. 2007).

The order–disorder alterations occurring on heating of an aqueous suspension of starch granules is widely studied by using differential scanning calorimeter (DSC) (Jenkins 1994) which delivers the knowledge of gelatinization behavior of starches as onset temperature ($T_o$), peak temperature ($T_p$), conclusion temperature ($T_c$), and enthalpy of gelatinization ($\Delta H_{gel}$). Krueger et al. (1987) reported that starch transition temperatures and enthalpy of gelatinization given by DSC may be related to the degree of crystallinity of starch granules. Gunaratne and Hoover (2002) reported that the gelatinization of starches is influenced by starch composition, amylopectin structure and crystalline to amorphous ratio of starches. $T_p$ indicates the qualitative behavior, while $\Delta H_{gel}$ measures the quality as well as quantity of crystallite and indicates the loss of crystallite order within starch granule (Hoover and Vasanthan 1994). Singh and Singh (2003) reported that rigidity in structure of granules and existence of lipids may have caused the elevation in transition temperatures of rice and corn starches. DaSilva et al. (1997) studied the effect of granule size on rheological behavior of corn starches and also concluded that the difference in the extent of swelling as well as rigidity of granules may cause the variation in their rheological activities. Mweta et al. (2008)
observed a significant negative correlation between gelatinization enthalpy and amylose content of starches.

Due to thermal instability, the swollen starch gel is converted into an inelastic structure on cooling, due to rearrangement of amylose and the collective term for these changes is “retrogradation” (Ottenhof and Farhat 2004). During retrogradation, the reassocation of molecular chains due to H-bonding in gelatinized starch paste takes place (Hoover 2001). Amylose forms double-helical structure comprised of 40-70 glucose units (Jane and Robyt 1984), while crystallization of amylopectin takes place due to the reassociation of the outermost short branches (Ring et al. 1987). Higher retrogradation affinities are accredited to the crystallization comprising small amylose molecules and long chain amylopectin (Peroni et al. 2006). Retrogradation of starches is increased by continual freezing and thawing of paste (Leszczynski 2004). Both amylose and amylopectin undergo retrogradation, but amylopectin seems to play a major part in changing the quality of foods (Miles et al. 1985). Gudmundsson (1994) reported that amylose plays role in short term changes during retrogradation, whereas deviations in amylopectin are the major basis of retrogradation that is accountable for long term structural variations.

Sasaki et al. (2000) observed that the retrograded starches display lower gelatinization as well as enthalpy than native starches because of weaker crystallinity of retrograded starches. Whistler and BeMiller (1996) reported the role of amylose, while Conde-Petit et al. (2001) and BeMiller (2011) studied the role of amylopectin and intermediate materials in starch retrogradation during refrigerated storage. Wu et al. (2010) studied the effect of proteins on retrogradation that forms the complex with starches and hence inhibits the process. Fu et al. (2015) reported that certain constituents like carbohydrates, salts and polyphenols have significant effect on retrogradation of starches in addition to proteins and lipids. Tziotis et al. (2005) studied the thermal and retrogradation behavior of corn starch from normal and mutant genotypes and observed the role of amylose and amylopectin in DSC parameters. Kuakpetoon and Wang (2007) also reported the role of amylose content, amylopectin chain length, amorphous and crystalline regions on transition temperatures and enthalpies of gelatinization and retrogradation of waxy and normal corn starches. Ji et
al. (2003b) found a strong correlation of DSC parameters of starches from different corn lines with the proportion of large granules with average diameter of ≥ 17 µm.

**2.4.2.5 Scanning Electron Microscopy (SEM)**

Sujka and Jamroz (2013) reported the SEM images of corn starch granules showing irregular shape with large number of pores or furrows on their surface and also, certain starch granules with totally smooth surfaces. Perera *et al.* (2001) reported that the SEM analysis of starch from normal and waxy corn showed the angular or spherical shape of granules with smooth surfaces. Błaszczak *et al.* (2005) observed a polygonal shape of waxy corn starch granules ranging in size from 2 to 30 mm in SEM analysis. Li *et al.* (2001) viewed the occurrence of “pin holes” and equatorial grooves or furrows in large-sized corn starch granules. Forssell *et al.* (2003) described that the pores present in starches acts as adsorbents for various components including proteins, enzymes, peptides and even microbes. Koo *et al.* (2010) reported the effect of cross linking on the granular structure of corn starches and detected a black zone on the exterior of cross linked starch granules having rough surface to some extent through SEM, while the shape of native starch granules was reported to be polygonal. Dombrink-Kurtzman and Knutson (1997) used SEM to differentiate the surface appearance of starch granules from soft and hard endosperm, with arbitrarily allocated pores on the starch granules surface from soft endosperm, while few pores on surface of granules from hard endosperm. Singh *et al.* (2003) reported significant differences in size and shape of the starch granules from corn, rice, potato and wheat during SEM imaging. Xie *et al.* (2006) suggested that the citric acid treatment to the corn starches could directly enter a loosely organized central region of starch by cavities and pinholes, which cause changes in the granule morphology.

**2.4.2.6 X-Ray diffraction (XRD)**

X-ray diffraction determines the gelatinization of starch, where the complete obliteration of crystallite integrity is detected as a function of moisture content and temperature (Zobel *et al.* 1988). The “A-,” “B-,” and “C-type” patterns examined by X-ray diffractogram designate the difference in amylopectin double helical packing (Singh *et al.* 2014a). Corn starches display a typical A-type pattern (Tziotis *et al.* 2005), in
which double helices encompassing the crystallites are compactly packed with low water content. High crystallinity of waxy corn starches than normal cereal starches was reported earlier (Vandeputte et al. 2003).

X-Ray diffraction studies suggest that intermolecular association involves a crystallization process (Ring et al. 1987). A-type X-ray patterns were reported to be displayed by normal and waxy corn starches (Perera et al. 2001) as well as native and cross linked corn starches (Koo et al. 2010). Wang et al. (2003) reported that the increase in concentration of acid in starches caused an increase in the degree of crystallinity, might be due to massive hydrolysis. On the other hand, Xie et al. (2006) reported a disruption of crystalline structure of corn starch granules due to penetration of concentrated citric acid in the cavities. Ji et al. (2003b) studied the X-Ray diffraction pattern of starches from different corn lines and reported that all starches had A-type pattern, indicating the similarity in starch granules packing among different varieties.

2.5 Processing behavior

Dry milling of corn produces the grit and flour fractions of different size that vary in composition as well as end use suitability (Singh et al. 2009a). “Cornflakes” are made from flaking grits, while extruded foods ranging from breakfast cereals to snack foods are processed by using coarse and medium grits. Fine grits are used as brewing adjuncts (Singh et al. 2014a). Different bakery products such as muffin mixes and pan cakes are made by using coarse or granulated meal. Finely ground corn is used in the production of “tortilla,” a type of unleavened bread. Cornmeal or corn flour is used to make “roti” (chapatti) in northern states of India (Sandhu et al. 2007).

2.5.1 Corn Extrusion

The production of ready-to-eat foods has increased due to high consumption and extensive demand of such products in food market. A well-established thermal technology used for fabrication is extrusion that gives higher productivity in less time (Morsy et al. 2015). Extrusion processing has various unique features and benefits including high efficiency, low cost of operation, versatility, and many final products of desired size, shape, texture and sensory properties at very low processing cost (Faraj et al. 2004; Thymi et al. 2005). Consumer preferences designate that extrudates should
have porous structure, crunchy texture, a large amount of thin-walled air cells, a high degree of expansion and low specific density (Kasprzak et al. 2013). Due to good expansion characteristics, cereals are primarily used for the production of extruded snacks. Corn grit is a major ingredient of commercial extruded foods and is manufactured by successive reduction stages of dry milling (Singh et al. 2009a). Wang and Ryu (2013) reported that raw materials undergo several physicochemical changes during extrusion, including change in color, starch gelatinization and denaturation of protein. Robutti et al. (2002) observed that the corn grits with hard endosperm gave better expansion and lesser energy consumption than the grits with soft endosperm during extrusion. Lee et al. (2006) reported the effect of endosperm texture of corn grits on extrusion behavior and extrudate characteristics. Gujral et al. (2001) explained that the corn type had a significant effect on water solubility index and expansion of the extrudates, where the grits with more fine particles had lower water solubility and expansion. Zhang and Hoseney (1998) found that extrusion of coarse corn grits with large particle size produced the extrudates with poor expansion. For the production of good quality and puffed end products, the properties of raw material used must be regulated as these plays an important role in determining the extruder behavior (Chang et al. 1998).

Feng and Lee (2014) reported that specific mechanical energy (SME) can be used to indicate the extrusion conditions as well as certain properties of extrusion products like expansion, solubility, and density. Liang et al. (2002) studied the correlation of efficiency and the SME of extruder with the screw speed and specific feeding load during extruding corn meal using twin screw extruder. They reported that the SME decreased while extruder efficiency increased with increase in feed rate. Lazou and Krokida (2011) observed a decrease in SME and increase in water solubility index with increase in extrusion temperature during extrusion cooking of corn-lentil extruded snacks. Baik et al. (2004) reported that the different barrel temperatures during extrusion resulted into the extrudates with more expansion and less water absorption index as compare to that of a constant extruder barrel temperature.

Paes and Maga (2004) studied the extrusion behavior of quality protein maize (QPM) and normal corn flours and observed the effect of extrusion on lightness, redness
and yellowness of extrudates. The high temperature and low water conditions during extrusion are known to cause the Maillard reaction during which the reducing sugars react with certain amino acids, which leads to the formation of color components and reduction in the available amine group of lysine (Camire 2000). The variation in the structure as well as the degree of expansion of extrudates during extrusion is highly dependent upon the process parameters and physical characteristics of extrusion formula (Barrett 2003). The quality of extruded products is determined by chemical and structural changes during extrusion. These include denaturation and cross-linking of proteins, starch depolymerization, loss of starch crystallinity, complexation between polar lipids and amylose, and degradation reactions by polymers and other molecules (Moisio et al. 2015).

Phenolics present in free and bound form are known to be used for the prediction of end-use suitability of cereal products (Naczk and Shahidi 2006). Viscidi et al. (2004) studied the effect of addition of certain natural phenolics on extruded cereal products and reported that phenolic compounds could be used as antioxidants in extruded foods. Camire et al. (2007) made corn extrudates by adding fruit powder in order to increase the anthocyanin, antioxidant and sensory properties of final product and observed an enhancement in functional characteristics of final products. Camire et al. (2005) studied the effect of blending antioxidant rich plant materials in degemerd cornmeal on preventing the oxidation of final extruded products.

Extensive work on analyzing the extrusion behavior of corn after blending with different raw materials like, lentils, common bean, whey products, soya, beetroot etc. has been done previously (Liu et al. 2000; Li et al. 2005; Lazou et al. 2007; Anton et al. 2009; Singh et al. 2016a). Seth et al. (2015) also studied the effect of feed moisture, extrusion temperature and feed composition on extrudate properties of yam, corn and rice blends. Onwulata et al. (2001a) studied the effect of co-extruding wheat fibre and milk proteins with corn flour meal in order to get the expanded products. Singh et al. (2015) reported that beetroot powder incorporation in corn grit and extrusion temperature had significant effects on mouthfeel and overall acceptability of extrudates. Liu et al. (2000) observed that the expansion of oat-corn extruded puffs was highly correlated with the moisture, screw speed and temperature, where corn related flavor
development was likely due to high screw speed and temperature. Also, they found good correlations between physical and sensory characteristics of oat-corn puffs. Ding et al. (2005) studied the effect of extrusion on physicochemical and sensory properties of rice based extrudates, where increase in extrusion temperature caused an increase in expansion, water solubility index and crispiness of extrudates. Singh et al. (2000) studied the effect of sodium bicarbonate and glycerol monostearate addition on extrusion behavior of corn grits extruded at variable temperatures.

Ibanoglu et al. (2006) explained that the color, flavor and sensory attributes of gluten free extruded snacks did not show any change with variation in feed rate and screw speed during extrusion. Thakur and Saxena (2000) statistically formulated and studied the effect of blending corn flour and green gram flour with different gums on sensory and expansion characteristics of extruded snack food. Chen et al. (1991) reported a highly significant effect of extrusion temperature and feed moisture on texture and sensory properties viz. hardness, crispiness, chewiness, aroma, flavor of extrudates made from yellow corn meal. Santosa et al. (2008) demonstrated that water absorption plays a fundamental role in volume expansion, color, texture, and sensory attributes of extrudates.

2.5.2. Corn dough and chapatti properties

During chapatti making, the dough preparation requires dry flour mixed with an appropriate amount of water to form a coherent mass by doing mechanical work in order to get acceptable product (Hoseney and Finney 1974). The corn flour is found less acceptable for baked products due to lack of storage proteins exhibiting viscoelasticity in dough Shewry et al. (2002). Yet, corn based products are seeking demand as a gluten free alternative substitute due to high prevalence of gluten sensitivity or celiac disease (Fasano et al. 2003; Torbica et al. 2010). The major protein fraction in corn kernel is zein that is a prolamine and provide viscoelasticity to dough at >20 % moisture and mixed at 35 °C temperature (Lawton 1992). Sinha and Sharada (1992) used alkali treatment for comparing chapatti-making behavior of corn flours with untreated samples to report the acceptability of chapatti. Petrofsky and Hoseney (1995) observed that different flours required different amount of water as well as different mixing time for
optimum dough development. Caballero-Briones et al. (2000) reported that the prepared corn dough is used for formulating various products like taco, shells and snacks such as corn chips and tortilla and Mexican foods.

For studying the mixing behavior and for measuring the quality of flour, mixograph is one of the most commonly used instruments in baking industry (Singh et al. 2016b). On mixing the flour with water, the formation of homogeneous mass, development of protein network and incorporation of air cells in dough has been accomplished (Seabourn et al. 2008). During dough formation, water plays an important role in case of flour as water is necessary for a) solubilisation of other ingredients, b) carbohydrates and proteins hydration c) starch-protein network development (Maache-Rezzoug et al. 1998). The complex role of water during dough development has been reported by Eliasson and Larson (1993) and they stated that water affects the nature of interactions between the various constituents of ingredients, determines the conformational form of biopolymers and provide structure to dough. The essential role of water in determining the rheological behavior of flour doughs was studied by Webb et al. (1970). An increase in dough extensibility on addition of water was reported by Bloskma (1971).

Campbell and Shah (1999) described the intimate relationship between mixing and rheology, as the flour compounds are subjected to mechanical work they promote changes in their rheological properties. The mixing behavior of dough can be calculated using rheological testing that provides certain information to predict the quality of final product (Dobraszczyk and Morgenstern 2003; Rosell et al. 2007; Moreira et al. 2010). Dynamic rheology measures the viscoelasticity behavior of food, where storage modulus (G’), indicative of elasticity; loss modulus (G’’), indicative of viscosity of material; and tan δ (G’’/G’) the ratio of viscous and elastic moduli of sample are studied (Macosko 1994). To study these viscoelastic parameters, the equipment used is dynamic rheometer (Schirmer et al. 2015). G’ is the measure of accumulated energy and G’’ is the measure of the loss of energy in each deformation cycle and the modulus G’’/G’ is indicative of the behavior of the material, where the high value (>1) indicate liquid-like behavior, and low values (<1) indicate solid-like behavior (Waterschoot et al. 2015).
The dough rheology is affected by certain factors during the time after mixing which include the continued hydration of flour components, stress relaxation after mixing and water redistribution (Hibberd 1970).

Fourier transform infrared (FTIR) spectroscopy is a well-established technique for determining the protein secondary structure and chemical microstructure of foods (Wetzel and Reffner 1993). It is a flexible method of determining qualitative and quantitative information using very less amount of sample with minimal preparation (Ferreira et al. 2001). Duodu et al. (2001) studied the secondary structure of corn zein films and determined that protein was mainly in α-helical form along-with some β-sheet character. Cremer and Kaletunc (2003) studied the FTIR spectra for corn and oat flour based extrudates and observed the influence of lipids in spectral changes. Georget and Belton (2006) studied the effect of different levels of water content on protein secondary structure of wheat gluten and reported the changes in β-sheet structure. Seabourn et al. (2008) explained that increase in α-helix, β-turn and β-sheet secondary structures during mixing is an indicative of a more ordered conformation of dough proteins. They concluded from secondary structure analysis that infrared spectroscopic practices can be used to relate the rheological behavior of developing dough in a mixograph directly to the changes in structure of gluten protein system. Wetzel et al. (1980) reported that β-structures were formed during heat treatment which then increased on cooling and were correlated with albumin aggregation.

The dough made from cereal flours is further processed to produce different end-products such as bread, cookies, and chapatti. These processed products vary in color, expansion, texture, extensibility and overall acceptability. Sandhu et al. (2007) reported the rupture force, extensibility and color properties of chapattis made from flour of different corn varieties. Jan et al. (2000) reported that chapattis made from defatted soybean-wheat flour blends were acceptable but those made from rape seed and sunflower flours were unacceptable during sensory evaluation. Haridas Rao et al. (1986) observed that height of puffed chapatti and extensibility can act as simple indicator of the quality of chapatti. Gujral and Pathak (2002) studied the texture and sensory properties of chapattis made from composite flours where wheat flour was replaced with flours from rice, barley, corn in order to improve the taste, texture and
nutritional quality of end product. Lazaridou et al. (2007) prepared bread from gluten free formulations including rice flour and corn starch supplemented with different gums and reported a decrease in water activity ($a_w$) during storage. Gujral et al. (2004) studied the textural changes of rice chapattis by adding hydrocolloids and $\alpha$-amylase during storage and observed a decrease in extensibility with storage. Gujral and Gaur (2002) reported a decrease in extensibility of chapattis made from wheat flour during storage.

The review of literature indicated that limited work has been done on protein profiling, phenolics and milling properties of Indian corn germplasm. Also, literature on processing behavior of waxy corn is limited.