CHAPTER 2

LITERATURE REVIEW

2.1 MORPHOLOGY OF PEARL MILLET

The structure of the mature pearl millet caryopsis is very similar to that of sorghum caryopsis but with several differences (reviewed by Serna-Saldivar & Rooney, 1995). In comparison with sorghum, pearl millet is a smaller grain with a proportionally larger germ and consequently a smaller endosperm (Abdelrahman, Hoseney & Varriano-Marston, 1984). Pearl millet grain is reported to consists of 73.9-76.2% endosperm, 15.5-17.4% germ, and 7.2-10.6% pericarp (Table 1) (Abdelrahman, Hoseney & Varriano-Marston, 1984).

The pericarp of pearl consists of the epicarp, mesocarp, and endocarp and is of variable thickness. Cultivars with thick pericarps do not have starch granules in the mesocarp (reviewed by Serna-Saldivar & Rooney, 1995).

The sub-aleurone endosperm has a very dense protein matrix with only small starch granules in the first one or two cell layers (reviewed by Serna-Saldivar & Rooney, 1995). The corneous (horny or vitreous) area contains large, uniformly sized polygonal starch granules embedded in a protein matrix with small numbers of protein bodies. The respective average sizes of starch granules and protein bodies are 6.4-7.6 and 0.6-0.7 μm (reviewed by Serna-Saldivar & Rooney, 1995).

As stated, the pearl millet germ is proportionally larger than most other cereals. It contains an embryo and scutellum. Pearl millet scutellar epidermal or epithelial cells are very similar to those of sorghum (Zeleznack & Varriano-Marston, 1982). A dark pigmented material (black layer) is deposited

in the basal adgerminal (chalazal cells) surface of the grain during seed development (Fussell & Dwarte, 1980).

2.2 CHEMICAL COMPOSITION OF PEARL MILLET

Compared to sorghum and finger millet, pearl millet is notable for its relatively higher protein and oil levels, which are due to the large proportion of germ to endosperm (Tables 1 and 2) (reviewed by Serna-Saldivar & Rooney, 1995).

The starch content of pearl millet varies from 56 to 65% and the amylose content of the starch ranges from 17 to 29% (McDonough & Rooney, 1985). Table 3 summarises the starch properties of pearl and finger millets. Pearl millet starches have a higher amylose content and lower gelatinisation temperature than finger millet. The initial and end-point temperatures of starch gelatinisation are 59-63 °C and 68-70 °C, respectively (McDonough & Rooney, 1985). Pearl millet appears to require a higher temperature to initiate pasting or to develop viscosity than other cereal starches (Abd Allah, Mahmoud, El-Kalyoubi & Abou Arab, 1987). The water holding capacity of its starch is higher than that of sorghum but lower than that of maize. The swelling power and solubility are also higher than that of other starches (Abd Allah, Mahmoud, El-Kalyoubi & Abou Arab, 1987).

TABLE 1- Chemical composition of pearl millet and its anatomical parts

Component	Whole Grain (%)	Endosperm (%)	Germ (%)	Pericarp (%)
Whole kernel	100	75.1	16.5	8.4
Range		73.9-76.2	15.5-17.4	7.2-10.6
Protein	13.3	10.9	24.5	17.1
Percentage of total protein	100	59.5	31.2	9.4
Fat	6.3	0.5	32.2	5.0
Percentage of total fat	100	6.2	87.8	5.9
Ash	1.7	0.3	7.2	3.2
Percentage of total ash	100	13.9	72.2	13.9

Source: Abdelraham, Hoseney & Varriano-Marston (1984)

TABLE 2- Nutrient composition (proximate composition) of sorghum and millets

Cereal	Protein (%)	Fat (%)	Crude Fibre (%)	Ash (%)	NFE (%)	Starch (%)
Sorghum	11.0	3.2	2.7	1.8	81.3	70.8
Range	7.3-5.6	0.5-5.2	1.2-6.6	1.1-4.5	68.1-89.9	55.6-75.2
Pearl millet	14.5	5.1	2.0	2.0	76.4	71.6
Range	8.6-19.4	1.5-6.8	1.4-7.3	1.6-3.6	62.9-86.9	63.1-78.5
Finger millet	8.0	1.5	3.0	3.0	84.5	59.0
Range	6.9-10.9	1.0-4.6	2.0-6.8	2.3-3.9	73.8-88.7	ND

Source: Reviewed by Serna-Saldivar & Rooney (1995); NFE- Nitrogen-free extract; ND- Not determined.

TABLE 3- Properties of millet starches

Property	Pearl millet	Finger millet
Gelatinisation temperature (°C)	61-69	65-76
Amylose relative (%)	17.0-21.5	15-16
Amylopectin relative (%)	78.9-83.0	84-85
Starch		
Granule size (μm)	4.0-12.0	10-16
Form	Polygonal, round	Polygonal, round
Hilum	Large	Centric

Source: Reviewed by Serna-Saldivar & Rooney (1995).

The protein content of pearl millet varies widely; values ranging from 6 to 23% have been reported, with an average of from 10 to 13% (Lásztity, 1984). Concerning protein distribution between the different morphological parts of the kernel, the same rules are valid as in other cereal grains. The storage proteins (prolamin and glutelin) predominate (over 60% of the total protein). The albumin fraction averages 15% and the globulin 9% (Lásztity, 1984). The differences in amino acid composition between different morphological parts of the kernel are similar to other cereal grains (Lásztity, 1984). The amino acid composition of the proteins of pearl and finger millet is given in the Table 4. Among the most common tropical cereal crops, pearl millet is known to contain a higher protein content (Table 2) and better amino acid balance (Table 4) than sorghum (reviewed by Serna-Saldivar & Rooney, 1995). The higher ratio of germ to endosperm is responsible for the higher protein (Table 2), albumin, and globulin contents and improved amino acid composition. As in other cereals, the albumins and globulins are rich in lysine and tryptophan, whereas the prolamins are low in these essential amino acids (Table 4). According to Lásztity (1984), pearl millet prolamin apparently differs

markedly from that of the other cereals, being unusually high in tryptophan, although like that of other cereals pearl millet prolamin is rich in glutamic acid and proline and deficient in lysine (Table 5).

Cereal grains are rich source of dietary fibre. Most of the dietary fibre of millets is insoluble. Therefore the pearl millet fibre may decrease transit time and prevent gastrointestinal problems (reviewed by Serna-Saldivar & Rooney, 1995). The soluble dietary fibre is low which probably does not reduce blood cholesterol and arteriosclerosis as oat fibre does (reviewed by Serna-Saldivar & Rooney, 1995).

Osagie & Kates (1984) reported that the lipid content of pearl millet was 7.2% and consisted of 85% neutral lipids, 12% phospholipids, and 3% glycolipids. Neutral lipids contained approximately 85% triglycerides and small amounts of mono- and diglycerides, sterols, and free fatty acids.

Pearl millet is reported as being the cereal grain that most rapidly develops off-odours and flavours after milling (reviewed by Serna-Saldivar & Rooney, 1995). The reasons for the rapid deterioration are as follows: 1) high lipid content (Kaced, Hoseney & Varriano-Marston, 1984); 2) higher amounts of unsaturated fatty acids than other cereals; 3) insufficient naturally occurring anti-oxidants, and 4) high enzymatic-hydrolytic activity (reviewed by Serna-Saldivar & Rooney, 1995).

The off-odour precursor in pearl millet was found to be methanol soluble and had characteristics similar to apigenin, the aglycone of the major C-glycosylflavone present in pearl millet (Reddy, Faubion & Hoseney, 1986). However, Seitz, Wright, Waniska & Rooney (1993) reported that the mousy odour from raw pearl millet was due to 2-acetyl-1-pyrroline.

Millets are important sources of minerals and vitamins. The pericarp, aleurone layer, and germ are rich sources; therefore, in refined millet products part of these important nutrients will be lost (reviewed by Serna-

Saldivar & Rooney, 1995). Malting and fermentation, both primary processing technologies, are known to significantly increase phosphorus availability due to increased phytase activity (reviewed by Serna-Saldivar & Rooney, 1995).

TABLE 4- Amino acid composition of the proteins of millets (g/16 g N)

Amino Acid	Pearl Millet	Finger Millet
Essential		
Phenylalanine	4.4-5.6	4.4-8.4
Histidine	1.8-2.6	1.5-4.0
Isoleucine	3.6-5.9	3.8-8.5
Leucine	8.0-25.1	9.2-16.2
Lysine	1.7-6.5	2.6-5.5
Methionine	1.5-2.9	1.3-4.3
Threonine	1.2-4.8	3.5-5.8
Tryptophan	1.1-2.8	1.0-1.7
Valine	4.8-7.0	5.8-10.4
Non-essential		
Aspartic acid	4.9-10.3	6.5-10.0
Glutamic acid	12.3-25.4	20.3-37.8
Alanine	7.5-10.5	5.9-8.9
Arginine	3.2-8.1	3.8-8.2
Cystine	0.7-2.8	0.7-2.9
Glycine	2.8-5.8	3.6-5.9
Proline	5.9-14.2	4.2-10.1
Serine	3.7-5.6	5.1-8.7
Tyrosine	1.7-4.8	2.0-5.6
Amino acid score (%)	60.6	68.0

Source: Reviewed by Serna-Saldivar & Rooney (1995).

Millets are good sources of B vitamins, except for vitamin B-12 (Gazzaz, Rasco, Dong & Borhan, 1989). Dried, matured kernels do not contain vitamin C. The B vitamins are concentrated in the aleurone layer and germ (reviewed by Serna-Saldivar & Rooney, 1995). The alkali treatment used to produce tortillas, maize-based flat breads, which are traditional to Latin America, or *tô*, a food gel, improves bioavailability because the glycosidic bond that renders niacin unavailable is alkali labile. Malting increases the amount of B vitamins and their availability (reviewed by Serna-Saldivar & Rooney, 1995).

TABLE 5- Amino acid composition of the storage proteins of pearl millet (g /16g N)

Amino Acid	Prolamin	Glutelin
Lysine	1.66	2.14
Histidine	2.14	1.64
Arginine	3.04	4.92
Aspartic acid	7.48	6.36
Glutamic acid	22.24	21.68
Serine	6.12	5.35
Threonine	3.46	2.92
Cystine	1.42	1.34
Methionine	1.02	1.34
Phenylalanine	3.82	4.94
Glycine	1.23	2.74
Alanine	9.41	10.42
Valine	3.24	4.12
Proline	10.23	9.42
Tyrosine	4.62	4.44
Isoleucine	3.32	3.83
Leucine	12.06	10.18
Tryptophan	2.84	0.69

Source: Lásztity (1984)

Fat soluble vitamins are mainly located in the germ of pearl millet. It is a good source of tocopherols (vitamin E); but only kernels with yellow endosperm contain some provitamin A activity (reviewed by Serna-Saldivar & Rooney, 1995).

Non-germinated cereals indigenous to the tropical and subtropical areas of the world such as pearl millet and sorghum have no more than traces of either of the starch degrading enzymes α- and β-amylase (Novellie & De Schaepdrijver, 1986). Good amylase activity of grain is desirable to obtain solubilisation of starch and its subsequent conversion to maltose (Jain & Date, 1975). Germination leads to the production of both amylases with α-amylase predominating. The diastatic activity of pearl millet is between 1.18-5.65 times higher than that of barley (Jain & Date, 1975). Sheorain & Wagle (1973) reported that β-amylase activity in pearl millet reaches a maximum value after 30 h of germination whereas at 72 h it is almost equal to that at zero time. Later, Pal, Wagle & Sheorain (1976) reported that barley malt has higher amount of maltose than pearl millet and that both pearl millet and barley malts have comparable amylolytic as well as proteolytic activities. These authors did not find significant differences in enzyme activities of the two malts. Sheorain & Wagle (1973) reported that α-amylase activity is eight to fifteen times greater in pearl millet malt than in wheat malt. Millet amylase shows higher amylolytic action on wheat starch than on millet starch (Klopfenstein & Hoseney, 1995). High amylase activity in millet flour probably is responsible for its improving effect in wheat flour breads (Klopfenstein & Hoseney, 1995).

2.2.1 Nutritive Value of Pearl Millet

The nutritional properties of pearl millet have received more attention than those of the other common millets, because it is the largest-seeded, most widely grown type (Hoseney, Andrews & Clark, 1987).

Protein digestibility and lysine content of pearl millet are higher than those of sorghum and comparable to those of maize (Serna-Saldivar, McDonough & Rooney, 1990). In contrast to sorghum, pepsin digestibilities of pearl millet and maize do not decrease as much upon cooking (Serna-Saldivar, McDonough & Rooney, 1990).

Although lysine is the most limiting amino acid in pearl millet protein, quite a range of concentrations has been reported, with values at the higher end of the range (3.6 g/100 g protein) as high as that for opaque-2 (high lysine) maize (Badi, Hoseney & Casady, 1976). Except for its lysine deficiency, pearl millet has well-balanced protein, with higher concentration of threonine and lower (but adequate) leucine than sorghum protein (Klopfenstein & Hoseney, 1995). Tryptophan levels are generally higher in pearl millet than in other cereals (Chung & Pomeranz, 1985).

Other important nutritional aspect of pearl millet is the fact that this grain cereal is rich in polyunsaturated fatty acids (PUFAs), which are believed to lower blood cholesterol levels (Potter & Hotchkiss, 1995).

2.2.2 Antinutrients in Pearl Millet

Like other cereals, pearl millet is reported to contain considerable amounts of phytic acid, representing more than 70 % of the total phosphorus in the grain (Chauhan, Suneja & Bhat, 1986). The antinutrients, mostly polyphenols and tannins, present in pearl millet are concentrated in the bran (reviewed by Klopfenstein & Hoseney, 1995).). Hulse, Laing & Pearson (1980) reported phytic acid levels from 208 to 246 mg in finger millet and from 170 to 470 mg in proso millet.

In general, the phytic acid is destroyed during pearl millet grain germination (Sebolev, 1962 according to Klopfenstein & Hoseney, 1995) when the enzyme phytase is synthesized and activated. After 48 h germination with devegetation of the malt, the percentage of phosphorus as phytate phosphorus in pearl millet decreased from 38 to 20% (Malleshi & Desikachar, 1986a). However, the reduction in phytic acid found by these authors may have been due to the fact that some of the phytic acid was removed with the roots and shoots during the devegetation process.

Pearl millet also contains oxalic acid (Opoku, Ohenhen & Ejiofor, 1981), which forms an insoluble complex with calcium, thereby reducing biological availability of the minerals (Whitney, Cataldo & Rolfes, 1987). Malting decreases the levels of oxalate from 0.520 to 0.068% (Opoku, Ohenhen & Ejiofor, 1981).

Epidemiological studies carried out in Sudan and reported by Klopfenstein, Hoseney & Leipold (1983) have suggested that pearl millet might be at least partly responsible for the higher goitre incidence in that country. It was then suggested that in pearl millet, the goitrogen is thioamide and/or other compounds derived from flavonoids such as C-glucosylflavones, vitexin, glucosylvitexin, and glucosylorientin (Birzer & Klopfenstein, 1988). Goitrogen is mainly found in the bran (Klopfenstein, Hoseney & Leipold, 1983b) and it is

believed to produce goitre due to the inhibition of the normal conversion of thyroxine (T4) to triiodothyronine (T3) (reviewed by Serna-Saldivar & Rooney, 1995). Hence, the elimination of the possibility of occurrence of mousy odour should be an advantage in the reduction of goitre incidence in the countries where pearl millet is a staple food.

Pearl millet contains two trypsin inhibitors with molecular weights around 11,000 Da (Chandrasekhar & Pattabiraman, 1981). These authors reported that the inhibitors are resistant to pepsin and α-chymotrypsin but are partially inactivated by pronase treatment. They also found both inhibitors fairly heat-stable and stable also to exposure to a wide pH range of 1-9.

2.3 MALTING OF CEREALS

With increasing dependence upon cereal grains to provide both the energy and protein requirements of humans in developing countries, the need for raising the overall nutritional status of cereal grains has become increasingly important, and much effort has been made to improve the amount and quality of cereal proteins by using processing techniques such as malting and fermentation. Malting is a technique that can effect positively the physicochemical composition of cereals by improving their nutritional value (reviewed by Chavan & Kadam, 1989).

2.3.1 Malting Technology

The terminologies, viz., sprouting, malting, and germination, are often used interchangeably in the literature to describe the process of soaking or steeping the dry grains in water until they are saturated followed by germination under controlled conditions for a specific period (Briggs, Hough, Stevens & Young, 1981; reviewed by Chavan & Kadam, 1989). Here the technologies used to malt sorghum will be described primarily, because of their relevance to malting pearl millet.

Malting involves essentially the limited germination of cereal grains in moist air under controlled conditions. The main objective of the malting process is to mobilize the grain's endogenous hydrolytic enzymes, particularly the amylases for the breakdown of starch into fermentable sugars (Taylor & Dewar, 2001).

According to Briggs, Hough, Stevens & Young (1981) and Briggs (1998) it is useful to consider malting as consisting of three stages:

1) Steeping or soaking of the grain;
2) Germination, i.e. seedling growth and
3) Drying.

The metabolic processes of germination are initiated during steeping by immersing the grain in water and allowing it to imbibe a suitable amount of water. During the phase of germination, the moist grain is allowed to grow in a humid atmosphere under controlled conditions. When the degradation of the endosperm, which naturally sustains the development of the growing embryo during germination, has progressed to only a limit extent, both the degradation and the growth of the germ is terminated to produce a shelf-stable product, by the process of drying (Briggs, Hough, Stevens & Young, 1981).

The malting process is initiated by steeping. The main objectives of steeping are to hydrate (enzymes need water to be active) the dry, resting grain sufficiently to initiate the metabolic process of germination and to clean the grain by washing, removing the dust and light grains (floaters) (Briggs, Hough, Stevens & Young, 1981; Briggs, 1998). The process of steeping is carried out until the water content of the cereal grain rises to the desired level. The temperature of the water in which the grain is steeped is crucial on the rate of water absorption of the cereal grain (Dewar, Joustra & Taylor, 1993).

In the case of sorghum, in South Africa for instance, commercial malting is generally performed using one of two processes (*viz* Floor Malting and Pneumatic Malting) (Dewar, Joustra & Taylor, 1993; Dewar, 1997; reviewed by Taylor & Dewar, 2001). In both malting processes the steeping stage is common.

The most common types of steeping vessels are called self-emptying and self-cleaning devices and are made from steel and are cylindrical or rectangular in cross-section; with conical bottoms at an angle of at least 45-50 ° from the horizontal which allow the grain to slide out either by gravity or by using pumps (Briggs, Hough, Stevens & Young, 1981; Briggs, 1998; Dewar, Joustra & Taylor, 1993). In most cases with sorghum, temperature control is not available. However, some of steeping vessels are equipped with a means of warming the steep water to a fixed temperature, i.e. the steep water temperature cannot be changed much once established. These vessels can be filled with water from bellow or above and the grain can be loaded by running it down a chute from an overhead silo.

Several factors influence the rate of water uptake during steeping. The so-called steeliness (vitreousness, corneousness, glass)/mealiness (floury) character of the starchy endosperm appears to be of particular importance (Palmer & Harvey, 1977; reviewed by Palmer, 1989). The temperature of the water at steeping is also relevant, since moisture uptake is more rapid at elevated temperatures (Macey, 1977; Lewis & Young, 1995; reviewed by

Briggs, 1998). Besides water, the grain requires a supply of oxygen to support respiration. Oxygen access may be inhibited if the grain is submerged in water for prolonged periods. Air rests, a period during steeping where the grain is not immersed in water, serve the added role of removing carbon dioxide and ethanol, which may inhibit germination. Aeration is also achieved by blowing compressed air through the water during the submerged steep periods.

The visual signs of germination (seedling growth) are the elongation of the radicle and emergence and elongation of the acrospire. The appearance of the white "chit", the coleorhiza or root sheath are the first indication of germination, which may occur at the end of steeping or shortly after casting the grain onto the germination bed (Briggs, Hough, Stevens & Young, 1981; Dewar, Joustra & Taylor, 1993; reviewed by Briggs, 1998).

Although the steeping step is common to both floor and pneumatic malting of sorghum, the germination and drying steps are different. Under outdoor floor malting conditions, the grain is malted outdoors in the traditional way in relatively thin layers on a concrete floor. In this process, the control of the conditions of germination appears to be difficult. Consequently the quality of the malt produced tends to be low and inconsistent (Taylor & Dewar, 1992; reviewed by Dewar, 1997). Sorghum malt of high and consistent quality is required when it is used as an ingredient in industrial brewing. Today, most of the sorghum malt used in factory brewing is malted indoors in modern pneumatic industrial installations. In South Africa, the Saladin box type maltings are generally used to carry out pneumatically sorghum malting (Dewar, Joustra & Taylor, 1993). This system has a rectangular chamber on top of a perforated steel false floor on which the sorghum is germinated, below which is a second chamber or plenum. Fans are used to blow air into the lower chamber and then up through the false floor and subsequently through the bed of germinated grain (Dewar, Joustra & Taylor, 1993; Briggs, 1998).

The relative merits of the utilisation of a floor over a pneumatic maltings in developing countries are the fact that pneumatic maltings are very expensive. Furthermore, the equipment, particularly the fans and turners, require regular and fairly sophisticated maintenance. They require electricity, coal, oil or gas. Contrarily, floor maltings do not require expensive construction, sophisticated maintenance and use solar energy (Taylor & Dewar, 2001). However, pneumatic maltings have a merit over floor malting in producing better quality malt (Taylor & Dewar, 2001). Probably, floor malting is most suitable for pearl millet, particularly in view of the small size of the grain, which is known to fall through the perforated false floor.

After a germination stage sufficient to achieve even modification, the "green malt" is dried to arrest germination and stabilize the malt by lowering moisture levels, typically to less than 10% (Bamforth & Barclay, 1993). During the drying process the growth of the green malt, which was promoted by the biochemical and physical changes, is stopped and the seedling dies by the flow of hot air (Dewar, Joustra & Taylor, 1993; reviewed by Briggs, 1998).

In the process of drying, undesired raw flavours are removed with high drying temperatures (kilning) and pleasant "malty" notes are introduced (Bamforth & Barclay, 1993). The process of kilning is also responsible for the development of malt colour. To ensure survival of enzymes, the drying process must be carefully regulated since the enzymes are crucial in the brewery or distillery to hydrolyse the malt starch into fermentable sugars (Bamforth & Barclay, 1993).

In floor malting, the malt is generally dried by exposing it directly to the sun. The malt is spread into a thin layer and is turned intermittently. Some floor malting plants use mechanical drying to dry the malt. The mechanical drying process involves a flow of warm dry air from a furnace which is passed through the malt. This process is also mostly used in pneumatic maltings. Some maltings use the same germination box to dry the malt, whilst others dry the malt in a separate drying chamber (Dewar, Joustra & Taylor, 1993;

Briggs, 1998). The advantage of the former system is that it "sterlises" the germination box.

As stated, in southern Africa, very little pearl millet malting is carried out at a commercial level. In Mozambique, pearl millet malting is only carried out at the household level as for floor malting. The grains soaked in a clay pot (called *hotso* in Rhonga and Shangaan) and only removed after chitting has occurred. The steeped grains are then germinated by spreading out on a sack bag, which is placed on the floor and covered with an other sack bag. The germinating grains are periodically watered. After 3 to 5 days of germination the cover bag is removed and the green malt is usually placed on the roof, for direct exposure to the sun, to dry. These malts are ground by pounding and mostly used to prepare both opaque beers and soft porridges. When used in the production of traditional beers, they are used with rice grits as the starchy adjunct, which differs from sorghum beer preparation, where maize is used as starchy adjunct.

2.3.2 Malting Science

As described, malting is similar irrespective of the foodstuff for which the malt is intended. The steeping of the grain in water to achieve a moisture level sufficient to activate metabolism in embryonic and aleurone tissues, leading in turn to the development of hydrolytic enzymes initiates the process of malting (reviewed by Bamforth & Barclay, 1993). Moisture uptake into the starchy endosperm is also critical before the food reserves of that tissue can be mobilized through the action of the enzymes. The enzymes migrate through the starchy endosperm, progressing from the embryo end of the kernel to distal end (Bamforth & Barclay, 1993). In barley, the mobilization phase is generally referred to as "modification", the cell walls and protein matrix of the starchy endosperm are degraded, exposing the starch granules and rendering

the grain friable and readily milled (Briggs, Hough, Stevens & Young, 1981; Bamforth & Barclay, 1993; Briggs, 1998).

At the beginning of steeping, the embryo and husk (in the case of barley) absorb water far more rapidly than does the starchy endosperm. It seems that water uptake is regulated by the embryo, although the mechanism by which it does this is still unkown (Briggs, Hough, Stevens & Young, 1981; Bamforth & Barclay, 1993; Briggs, 1998).

To produce homogeneous malt, it is necessary to achieve an even moisture content across the grain bed. Hence, the steeping operation is the most critical stage in the malting process. Steeping conditions must take in to consideration the nature of the grain, i.e. cultivar, grain size, protein content and physiological conditions.

Mealy endosperms, characteristics of good malting grains, have a relatively open structure containing many cracks, and the starch granules are relatively loosely packed in the protein matrix. Water diffuses more readily through such an open structure than it does through a steely endosperm, which has tight protein-starch packing (Bamforth & Barclay, 1993). Thin kernels absorb water more rapidly than do larger ones.

Of all the plant hormones, or plant growth regulators, gibberellins, appear to be the most important in controlling, i.e. stimulating, of germination (Mayer & Poljakoff-Mayber, 1989; Fincher & Stone, 1993).

Gibberellins, produced by germinated barley embryos, induce the synthesis of α-amylase, which leads to the breakdown of the storage reserves of the endosperm and the transport of the substrates of liberation of energy to the metabolising embryo (Palmer, 1989; Fincher & Stone, 1993).

In barley, the germinating embryo produces gibberellins. Because these plant hormones stimulate the aleurone layer to produce and release the enzymes of modification including α-amylase, this is of crucial importance for the process of malting (Lewis & Young, 1995). In fact, this is probably the only desirable function of the embryo. Gibberellic acid can be applied during steeping to bolster the natural hormone and to accelerate modification (Lewis & Young, 1995). The embryonic axis synthesizes the gibberellins possibly from pre-formed precursors including *ent*-kaurene in the scutellum, and are released to stimulate the aleurone layer to synthesize enzymes (Lewis & Young, 1995). This formation and release of gibberellins takes place during steeping, i.e. in the first 2 days of embryo growth and the significant proximal-distal flow of water can carry the hormones with it through the endosperm to the aleurone (Palmer, 1989; Lewis & Young, 1995).

The gibberellins travel through the aleurone from the proximal to distal end in barley. In response to gibberellins the aleurone layer releases the bulk of the enzymes of modification with the scutellum making an early and useful contribution (Lewis & Young, 1995). Once the aleurone layer receives the chemical message delivered from the embryo in the form of the gibberellin hormones it responds with a massive increase of enzyme (protein) synthesis at the expense of the reserve substances (Lewis & Young, 1995; reviewed by Briggs, 1998). Alpha-amylase, endo-β-glucanases and proteases are formed. These enzymes play significant roles in endosperm degradation.

There have been reports that the application of gibberellic acid can promote shoot growth in sorghum (Morgan, Miller & Quinby, 1977; Rood, 1995). However, unlike the situation in barley, there is contradictory evidence as to whether the application of gibberellic acid to germinating sorghum grains increases amylase activity.

For many years authors believed that gibberellic acid does not stimulate amylase activity (Daiber & Novellie, 1968; Aisien & Palmer, 1983; Aisien,

Palmer & Stark, 1993). However, Agu, Okeke, Nwufo, Ude & Onwumelu (1993) and Nzelibe & Nwashike (1995) found that gibberellic acid has a stimulating effect on the diastatic activity of both sorghum and pearl millet. In sorghum, the stimulating effect of gibberellic acid appears to be variety dependent (Nzelibe & Nwashike, 1995).

Currently, sorghum malting practices rely almost entirely on the provision of suitable environmental conditions to initiate germination and promote the development of the essential malt hydrolytic enzymes (Morrall, Boyd, Taylor & Van der Walt, 1986; Dewar, Taylor & Berjak, 1997a).

As stated, in barley malting gibberellic acid can be used to stimulate the modification of the cereal grain during malting. Potassium bromate has been used to reduce the malting loss of pearl millet by reducing the respiratory loss while increasing the modification of the grain (Agu & Okeke, 1991; 1992; Agu & Ezeanalue, 1993).

Endosperm modification in barley and sorghum appears to differ. Nothing is known about pearl millet endosperm modification. In barley, modification is reported to commences at the proximal end of the grain, adjacent to the scutellum and proceeds, roughly parallel to the scutellar epithelium, from the proximal to the distal end of the grain (Gibbons, 1981; Ranki, 1990; reviewed by Fincher & Stone, 1993). It is believed that the major source of hydrolytic enzymes are the enzymes secreted from the scutellum which initially degrade the endosperm adjacent to the scutellum and as germination proceeds, the aleurone layer tissue (Gibbons, 1981). Although there has been great controversy regarding the relative importance of the scutellar epithelial and the aleurone cells in synthesising and secreting the endosperm-degrading enzyme into the endosperm (Palmer, 1989), many researchers accept that the aleurone layer is the tissue that is principally responsible for its synthesis (Ranki, 1990). Biochemical studies indicate that even with some aleurone contamination, the scutellum can account for less than 10 % of the α-amylase

found in the endosperm of barley malt (reviewed by Palmer, 1989). However, the scutellum synthesises, particularly during the early stages of endosperm mobilisation (McFadden, Ahluwalia, Clarke & Fincher, 1988), relatively high levels of another hydrolytic enzyme (*viz* β-(1→3), (1→4)-glucanase) (Stuart, Loi & Fincher, 1986). The latter authors also revealed that the relative contribution of the scutellum and the aleurone to the total hydrolytic activity of enzymes secreted into the starchy endosperm, thus varies according to the particular enzyme and to the time after the initiation of germination.

In sorghum, however, α-amylase is not synthesised in the aleurone layer. The evidence suggests that amylase are synthesised in the scutellum and then diffuse directly to the endosperm (Daiber & Novellie, 1968; Aisien & Palmer, 1983; Aisien, Palmer & Stark, 1983; Glennie, Harris & Liebenberg, 1983; Glennie, 1984). Similar findings, which showed that the degradative enzymes diffuse out from their origin in the scutellum, were found in wheat, rye, oats and maize (Okamoto, Kitano & Akazawa, 1980). Additionally, in sorghum the cell walls, aleurone layer and horny endosperm persist during germination (Glennie, 1984). Although it is known that during pearl millet germination, the α-amylase enzyme preferentially attacks the spherical granules instead of polygonal granules of the grain and that the starch hydrolysis is more vigorous at the centre of the granule than at the periphery (Hoseney, Varriano-Marston & Dendy, 1981); pearl millet grain structure during germination has received very little attention.

In tropical cereals, sorghum and pearl millet, differ from temperate climate cereals (barley) because they have no more than traces of β-amylase. (Novellie & De Schaepdrijver, 1986; Dufour, Mélotte & Srebrnik, 1992; Taylor & Robbins, 1993; reviewed by Zeigler, 1999). Beta-amylase is synthesized during temperate cereal (barley) development but is rendered fully active during germination (MacGregor, Gordon, Meredith & Lacroix, 1972; MacGregor & Lenoir, 1987; reviewed by Palmer, 1989; reviewed by MacGregor, 1996). Beta-amylase plays a crucial role during the mashing

phase of brewing because it is responsible for the degradation of starch and products of α-amylase hydrolysis of starch to maltose, the most abundant fermentable carbohydrate in wort (reviewed by MacGregor, 1996).

2.3.3 Malt Quality

Important quality parameters of malting include: grain germinability, α- and β-amylase activity, free α-amino nitrogen (FAN), malt extract and modification.

A pre-requisite to produce malt of a good and consistent quality is that a high proportion of the grain must germinate (Palmer, 1989; Bamforth & Barclay, 1993). This is measured as Germinative Energy (GE), which is a measure of the percentage of grains which can be expected to germinate if the grain is malted normally at the time of the test (European Brewery Convention, 1987). For sorghum, the recommended GE is 90 % after 72 h of germination (Dewar, Taylor & Joustra, 1995).

The single most important indicator of malt quality for opaque beer brewing is Diastatic Power (DP). DP is a measure of the joint α- and β-amylase activity of the malt. At the biochemical level, the combined action of α- and β-amylases, which develop during malting (Daiber & Novellie, 1968; reviewed by Palmer, 1989; Dufour, Mélotte & Srebrnik, 1992), is responsible for the breakdown of starch to fermentable sugars during the process of malting. Alpha-amylase attacks α- (1→4) glucosidic bonds within starch molecules to produce dextrins (short chains of glucose molecules) and a variety of sugars including maltotriose and maltose, and glucose. Being an endoenzyme, α-amylase rapidly solubilises starch to yield the smaller fragments, which is useful during the mashing stage in brewing, since it reduces the viscosity of the starch solution (reviewed by Palmer, 1989; Bamforth & Barclay, 1993; Lewis & Young, 1995). While β-amylase, an exoenzyme, releases maltose by hydrolysing the penultimate α- (1→4) glucosidic bond from the non-reducing

ends of the dextrins produced by the action of α-amylase (reviewed by Palmer, 1989; Bamforth & Barclay, 1993; Lewis & Young, 1995).

Free α-amino nitrogen (FAN) content, which consists of free amino acids and small peptides, produced by proteinase and peptidase activity in the malt, is an important component of malt quality, as it is required during the fermentation stage of the brewing process as a source of yeast nutrition (Baxter, 1981; Pickerell, 1986). Adequate FAN levels are especially important in lager beer brewing processes which use non-malted grain (sorghum or maize) with only a small amount of sorghum malt (Muts, 1991).

Malt hot water extract, which is a measure of the soluble solids in solution and gives an estimate of how much of the malt will solubilise during the brewing process (Briggs, Hough, Stevens & Young, 1981; Bamforth & Barclay, 1993; Briggs, 1998), is particularly important in lager beer brewing where, in some cases, an all-malt grist is used rather than an approximately 30 % malt grist which is generally the situation in opaque beer brewing (Palmer, 1989).

Modification, which is the term that signifies all the desirable changes that occur when grain is converted into malt (Briggs, 1998), is the measure of all the other malt quality parameters together. There are three aspects of modification, (1) accumulation of hydrolytic enzymes; (2) the variety of chemical changes that occur in the grains; and (3) the physical changes, which appear as a weakening and softening of the grains (Briggs, 1998).

2.3.4 Sorghum and Millet Malting

In barley, steeping is generally acknowledged as the most critical stage of the malting process (Briggs, Hough, Stevens & Young, 1981; reviewed by Briggs, 1998; reviewed by Taylor & Dewar, 2001). For many years, this malting stage

has been considered to be relatively unimportant for sorghum, finger and pearl millet. This perhaps because in sorghum and finger and pearl millet malting it is necessary to water the grain during the germination step, whereas in barley malting the grain must receive all the water it requires for germination during the steeping stage (Novellie, 1962a; reviewed by Taylor & Dewar, 2001). According to a review by Taylor & Dewar (2001), under controlled conditions, sorghum is steeped from 4-6 h to a maximum of 24 h. The optimum steeping time for finger and pearl millet, reported in the literature, is relatively short, i.e. between 6 and 16 h (Nout & Davies, 1982; Malleshi & Desikachar, 1986b, 1986c; Gomez, Obilana, Martin, Madzvamuse & Monyo, 1997; Muoria & Bechtel, 1998). The short steeping time used for finger and pearl millet may have to do with the smaller size of these grains compared to sorghum since smaller kernels have a proportionally larger surface area than larger ones.

Studies by Dewar, Taylor & Berjak (1997a) showed that as is the case for barley, the steeping stage is critical stage of the malting process for sorghum and that the conditions of steep should be controlled in order to optimise the quality of the resulting malt. The latter authors also found that the quality of malt, i.e. Diastatic Power (DP), free amino nitrogen (FAN) and hot water extract are significantly affected by steeping time and temperature. In addition, aeration during steeping has been found to further improve the quality of the malt produced in sorghum (Ezeogu & Okolo, 1995; Okolo & Ezeogu, 1995; Dewar, Taylor & Berjak, 1997a), in finger millet (Nout & Davies, 1982; Malleshi & Desikachar, 1986c) and in pearl millet (Gomez, Obilana, Martin, Madzvamuse & Monyo, 1997; Muoria & Bechtel, 1998). No studies have been reported to investigate the effect of steeping time and temperature on pearl millet malt quality.

Studies by many authors established the optimum conditions for the germination stage of sorghum malting (Novellie, 1962a; Morrall, Boyd, Taylor & Van der Walt, 1986; Dewar, Taylor & Berjak, 1997b; reviewed by Taylor & Dewar, 2001). In terms of both steeping (Dewar, Taylor & Berjak, 1997a) and

germination (Novellie, 1962a; Morrall, Boyd, Taylor & Van der Walt, 1986; Dewar, Taylor & Berjak, 1997b), the optimum temperature for sorghum, is between 24-30 °C. A temperature of 18 °C (and possible lower), reported as optimal for barley malting (Briggs, Hough, Stevens & Young, 1981; reviewed by Briggs, 1998), is considered suboptimal for sorghum (Dewar, Taylor & Berjak, 1997a), as are temperatures of 32 °C and higher (Morrall, Boyd, Taylor & Van der Walt, 1986). In the case of both finger and pearl millet, very little research has been done. Workers reported different optimum germination conditions for subsequent malt quality, 20-25 °C for 5-6 days (Nout & Davies, 1982, working with finger millet); 15-20 °C for 4-5 days (Malleshi & Desikachar, 1986b, working with finger millet); 22 °C for 3 days (Muoria & Bechtel, 1998, working with pearl millet) and 25 °C for 3-5 days (Gomez, Obilana, Martin, Madzvamuse & Monyo, 1997, working with pearl millet).

The moisture content of sorghum, both at the end of steeping (Dewar, Taylor & Berjak, 1997a) and of the green malt (malt prior to the drying process) (Dewar, Taylor & Berjak, 1997b) are positively correlated with malt quality in terms of DP, FAN and hot water extract. Therefore, for brewing purposes the moisture content of sorghum during the malting process is an important indicator of malt quality (reviewed by Taylor & Dewar, 2001).

Non-germinated sorghum grain shows virtually no β-amylase activity (Taylor & Robbins, 1993). Beta-amylase is influenced by germination time and temperature. A rapid increase in β-amylase activity occurs within the first 2 days of germination (Pal, Wagle & Sheorain, 1976; Taylor & Robbins, 1993) and subsequently declines in rate of increase up to 7 days (Taylor & Robbins, 1993). It is reported that β-amylase activity is inversely related to germination temperature over the 24-32 °C range, the highest activity being at 24 °C and 5 days (Taylor & Robbins, 1993).

Sorghum has little α-amylase in the non-germinated grains. Germination of sorghum leads to the production of both α- and β-amylases with α-amylase predominating. Morrall, Boyd, Taylor & Van der Walt (1986) and Dewar, Taylor & Berjak (1997b) found that the optimum conditions for high amylase activity in sorghum are germination at 24-30 °C for at least 4 days.

The proteolytic activity of pearl millet malt in 3- day germinated grains was found to be nearly eight times that of non-germinated grains (Pal, Wagle & Sheorain, 1976). Morrall, Boyd, Taylor & Van der Walt (1986) and Dewar, Taylor & Berjak (1997b) found that malting sorghum at 24-30 °C, for 6 days, at high watering treatment, gave optimum FAN. An increase in proteolytic activity during malting is desirable for nutritional improvement of cereals because it leads to hydrolysis of prolamins, and the liberated amino acids such as glutamic acid and proline are converted to limiting amino acid such as lysine (reviewed by Chavan & Kadam, 1989). FAN development is reported to vary among cultivars probably because of differences in major enzyme characteristics and rate of protein metabolism during sorghum malting as well as variations in grain protein structure and degradability (reviewed by Owuama, 1999). The reason for the increase of FAN during the malting process could be the fact that nitrogen is transferred from endosperm to embryos (axes and scutella). Nitrogen may also move from root to embryo by physiological mechanisms (Agu & Palmer, 1996).

During the germination phase, the moist grain is allowed to grow in a humid atmosphere under controlled conditions. When the degradation of the endosperm, which naturally sustains the development of the growing embryo (germ) during germination, has progressed to only a limited extent, the malster terminates both its degradation and the growth of the germ to produce a shelf-stable product, by drying the grain (Briggs, Hough, Stevens & Young, 1981; Taylor & Dewar, 1992; reviewed by Taylor & Dewar, 2001). In barley, the malt is kilned (rather than only dried), in that it is not only dehydrated, but partly cooked. This procedure partially or wholly destroys some of the

hydrolytic enzymes developed during malting. It also develops colour and flavour in the final product (Briggs, Hough, Stevens & Young, 1981). In tropical cereals like sorghum and pearl millet, however, because the hydrolytic activity of the malt (particularly the β-amylase activity) is inherently lower than that of barley (Novellie, 1960; Jayatissa, Pathirana & Sivayogasunderam, 1980; Aniche & Palmer, 1990), the malt is dried at a relatively low temperature (50 °C) as opposed to being kilned, as higher drying temperatures significantly reduce the already-low amylase activity (Novellie, 1962a; Okon & Uwaifo, 1985). The main aim of sorghum, finger and pearl millet malt is to conserve as much of the enzyme activity of the malt as possible whilst producing a shelf-stable product.

Alkaline steeping with final warm water steep in general improves substantially α-amylase activity in sorghum. However, in some cultivars it reduces it. The reason for this variation with cultivars is unclear but may be related to α-amylase polymorphism (reviewed by Owuama, 1999). Alkali is known to disrupt the molecular structure of the non-starch polysaccharides, which make up the cell wall (Verbruggen, Beldman & Voragen, 1995). It was suggested that NaOH disrupts the sorghum pericarp cell wall structure and, consequently allows water to enter the grain more rapidly during steeping, but not at a rate causing any significant imbibitional damage. Enhanced imbibitional hydration of the grain, brought about by steeping in dilute NaOH, could facilitate the onset of the stage of active metabolic activity more rapidly, thereby producing the malt quality required more quickly (Dewar, Taylor & Orovan, 1997; reviewed by Taylor & Dewar, 2001). Alkaline steeping causes a highly significant increase in sorghum malt FAN (Okolo & Ezeogu, 1996). No research has been reported on the effect of alkali treatment on the improvement of pearl millet malt quality parameters, probably because most varieties of pearl millet are low in tannins.

Exogenous GA_3, however, is not used in the sorghum malt industry, largely because of the evidence that its application does not significantly improve the amylase activity of this grain (Daiber & Novellie, 1968; Aisien & Palmer, 1983; Aisien, Palmer & Stark, 1983).

Earlier, Nout & Davies (1982) found that two levels of bromate (15 and 150 ppm) caused a reduction of approximately 30% malting loss in barley, however, the response in finger millet and sorghum was not significant. They also found that gibberellic acid treatment (0.2 ppm) was characterised by an accelerated development of α-amylase activity, resulting in increased diastatic power values.

Agu & Okeke (1991, 1992) and Agu & Ezeanalue (1993) studied the effect of potassium bromate and gibberellic acid on malting of pearl millet. They found that both additives, singly or in combination, improved the quality of pearl millet malt compared to untreated control. Potassium bromate was the most effective treatment followed by gibberellic acid and the combined treatment. Agu, Okeke, Nwufo, Ude & Onwumelu (1993) compared the effect of these additives on both sorghum and pearl millet. For millet the highest diastase and cellulase activities were observed on the 5th day of germination (0.20 mg/l gibberellic acid applied at steep-out), while sorghum showed highest activities of the enzymes on 4th day of germination for the same concentration of gibberellic acid.

Nzelibe & Nwasike (1995) reported that in two varieties of pearl millet, 12 ppm potassium bromate treatment did not significantly reduce the malting losses. However, at 120 ppm potassium bromate showed a significant reduction in malting losses in millet and sorghum at the 6th day of malting. These authors also reported that gibberellic acid stimulated the production and activity of diastatic enzymes in pearl millet and sorghum. The effect of gibberellic acid was apparent from the 2nd day of malting, corresponding to the mobilisation of natural gibberellins in the grain.

Germination significantly increases the total soluble sugars, reducing and non-reducing sugar contents of finger and pearl millet with a parallel decrease in its starch content, Malleshi & Desikachar (1986c) and Sripriya, Antony & Chandra (1997), working with finger millet and Opoku, Ohenhen & Ejiofor (1981) and Khetarpaul & Chauhan (1990a), working with pearl millet. Both soaking and sprouting periods have been found to influence the loss of starch and accumulation of sugars in sorghum. The soaking of grains for 10 h followed by sprouting for 24 h improved the starch digestibility significantly. However, prolonged soaking and germination beyond 10 and 24 h, respectively, apparently caused adverse effects on the susceptibility of residual starch to α-amylase (reviewed by Chavan & Kadam, 1989).

Malleshi & Desikachar (1986a) considered an increase in dietary fibre content, during malting of finger, foxtail and pearl millet for 4 days at 25 °C, as apparent and due to mainly the disappearance of starch. There is no indication that fibre components like cellulose and lignin are synthesized from carbohydrates during sprouting.

Malting has been found to decrease the fat content in sorghum germinated for 3 days at 25 and 30 °C by Aucamp, Grieff, Novellie, Papendick, Schwartz & Steer (1961) and Bhise, Chavan & Kadam (1988), respectively; in pearl millet germinated for 3 days at the temperatures of 22, 25 and 30 °C by Opoku, Ohenhen & Ejifor (1981); Opoku, Osagie & Ekperigin (1983); Mtebe, Nabikunze, Bangu & Mwanezi (1993) and Pawar & Pawar (1997) and in finger millet by Malleshi & Desikachar (1986a). The lipids of pearl millet grains are implicated in the decreased of its palatability. Hence, any reduction in fat content during malting will be advantageous, since it may contribute to an increase in pearl millet consumption.

Contradictory data have been reported on the effect of germination on the mineral (ash) content of cereals. When malting at 30 °C for 96 h, Wu & Wall (1980) observed a decrease in the initial 3 days of germination ash (mineral)

content of wheat, oats, and sorghum followed by an increase. However, no such differences or definite trends were observed for millets (Malleshi & Desikachar, 1986c) and sorghum (Aucamp, Grieff, Novellie, Papendick, Schwartz & Steer, 1961; Wu & Wall, 1980) during malting. An increase in ash content upon malting found by these authors is probably due to the loss of starch, while a decrease can be attributed to leaching losses during soaking and rinsing.

Sankara Rao & Deosthale (1983) reported that there were significant mineral losses when pearl millet is malted for 96 h at 25 °C: iron and manganese 40%, copper, 30%, and phosphorus, 25% and when finger millet is malted: calcium, 40%, zinc, 30% and copper, 25%.

Most reports agree that malting of cereal grains generally improves their vitamin value. However, the quantitative increase in each vitamin may be small and its practical significance in meeting the nutritional requirements of cereal-based diets is difficult to evaluate (reviewed by Chavan & Kadam, 1989). An increase in the content of vitamins of B-group through simple processing like sprouting is nutritionally desirable since cereal grains are an important source of these vitamins (reviewed by Chavan & Kadam, 1989). The sprouts obtained from maize, sorghum, finger millet and pearl millet have been reported to contain higher levels of niacin and riboflavin than the respective non-germinated grain (Aucamp, Grieff, Novellie, Papendick, Schwartz & Steer, 1961; reviewed by Chavan & Kadam, 1989). During malting of pearl millet for 96 h at 22 °C in the dark (Opoku, Ohenhen & Ejiofor, 1981) observed significantly higher values for riboflavin, thiamin, ascorbic acid, carotene, and tocopherol in the malt than in grains.

Data on changes in total protein content in cereal grains due to malting are contradictory. Some reports (Dalby & Tsai, 1976; Opoku, Ohenhen & Ejiofor, 1981); Taylor, 1983; Sripriya, Antony & Chandra, 1997) have indicated an increase while others (Hwang & Bushuk, 1973; Wu & Wall; 1980; Bhise, Chavan & Kadam, 1988; Subramaniam, Sambasiva, Rao, Jambunathan,

Murty & Reddy, 1995) have shown a decrease in protein content upon malting of cereals. Figure 1 gives data of changes in the protein content in several cereals grains during 5 days of malting at 28 °C in the dark (Dalby & Tsai, 1976). The total protein content increased steadily with time of malting in all cereals except the oats. Similarly, Hamad & Fields (1979), working with wheat; Wu & Wall (1980) and Taylor (1983), working with sorghum; Opoku, Ohenhen & Ejiofor (1981) and Sripriya, Antony & Chandra (1997), working with pearl and finger millet, respectively, reported an increase in protein content during malting. The increase in protein content has been attributed to loss in dry weight, particularly carbohydrates through respiration during germination.

Contradictory data were reported by Hwang & Bushuk (1973), working with wheat, Bhise, Chavan & Kadam (1988), Subramaniam, Sambasiva, Rao, Jambunathan, Murty & Reddy (1995), working with sorghum, and Opoku, Ohenhen & Ejiofor (1981), working with pearl millet, when studying loss in protein of the malts. The reduction in protein content is attributed to prolonged soaking of grains, where the protein may have been leached out.

The time of soaking the grains prior to germination and sprouting will greatly affect the changes in the protein fractions (Lorenz, 1980). Prolamin changes during malting for 5 days of some cereal grains are shown in Figure 2.

Taylor (1983) showed that the prolamins show the greatest decrease during malting of sorghum at 28 °C for 7 days, initially accounting for 45% of the total nitrogen in the grain, they decline to a mere 16% of their original quality. However, this author found that electrophoretic prolamin bands remained unchanged during malting which was the indication that prolamins are degraded directly to small peptides and amino acids. The glutelin fraction which accounted for some 27% of the total nitrogen in the non-malted sorghum declined to 57% of its original quantity after malting.

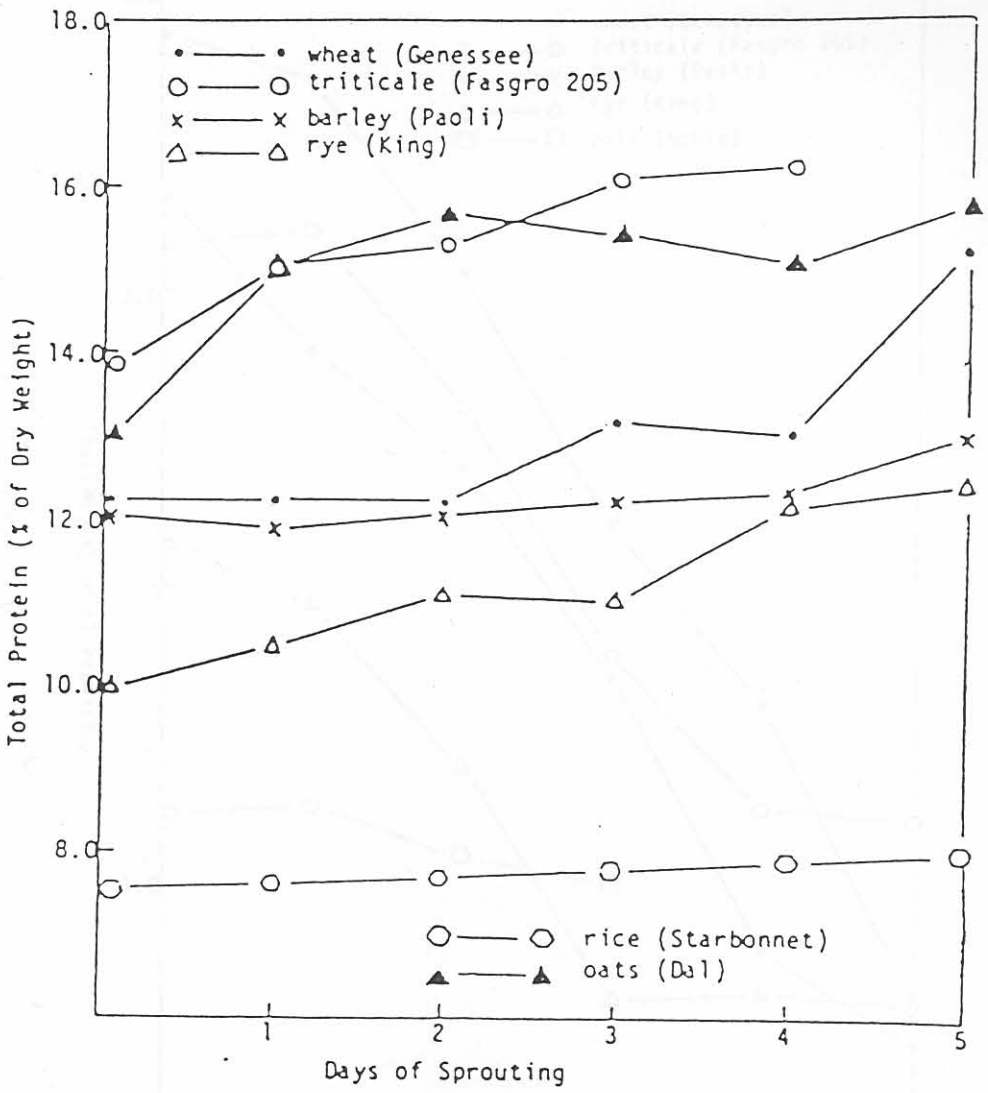

Figure 1- Changes in total protein during germination of cereal grains (Dalby & Tsai, 1976)

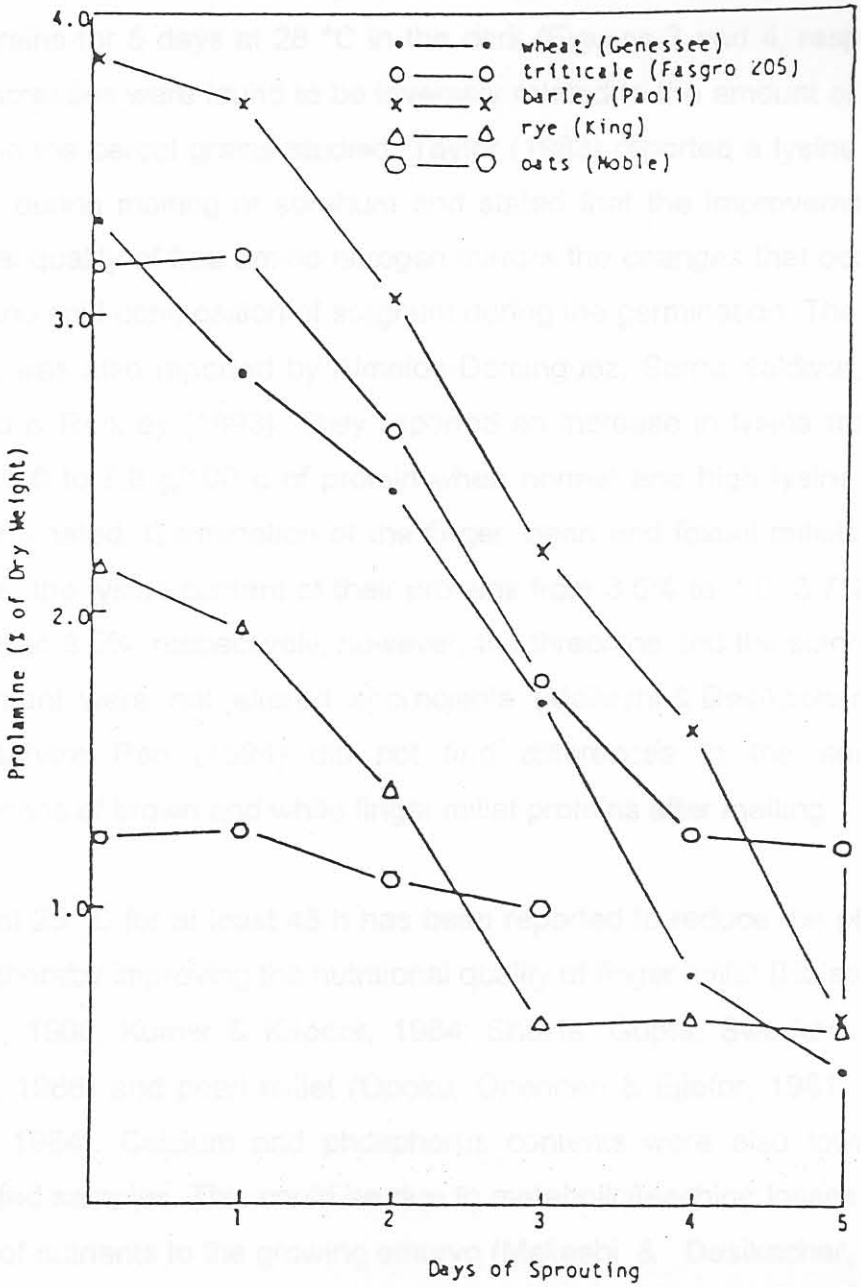

Figure 2- Changes in prolamin during germination of cereal grains (Dalby & Tsai, 1976)

Germination and sprouting increase the amounts of essential amino acids in cereal grains and that is of nutritional importance (Lorenz, 1980). Dalby & Tsai (1976) reported increases in lysine and tryptophan when germinating the cereal grains for 5 days at 28 °C in the dark (Figures 3 and 4, respectively). These increases were found to be inversely related to the amount of prolamin present in the cereal grains studied. Taylor (1983) reported a lysine increase of 4-fold during malting of sorghum and stated that the improvement in the nutritional quality of free amino nitrogen mirrors the changes that occur in the total amino acid composition of sorghum during the germination. The increase in lysine was also reported by Almeida-Dominguez, Serna-Saldivar, Gomez-Machado & Rooney (1993). They reported an increase in lysine from 2.2 to 3.2 and 3.0 to 7.8 g/100 g of protein when normal and high lysine-sorghum were germinated. Germination of the finger, pearl and foxtail millets for 48 h enhanced the lysine content of their proteins from 3.5% to 4.0, 3.7% to 4.3% and 3.0% to 3.5%, respectively; however, the threonine and the sulphur amino acid content were not altered appreciable (Malleshi & Desikachar, 1986a). Udayasekhara Rao (1994) did not find differences in the amino acid compositions of brown and white finger millet proteins after malting.

Malting at 25 °C for at least 48 h has been reported to reduce the phytic acid content thereby improving the nutritional quality of finger millet (Hulse, Laing & Pearson, 1980; Kumar & Kapoor, 1984; Shukla, Gupta, Swarkar, Tomar & Sharma, 1986) and pearl millet (Opoku, Ohenhen & Ejiofor, 1981; Kumar & Kapoor, 1984). Calcium and phosphorus contents were also lower in the germinated samples. This could be due to metabolic/leaching losses and also transfer of nutrients to the growing embryo (Malleshi & Desikachar, 1986a).

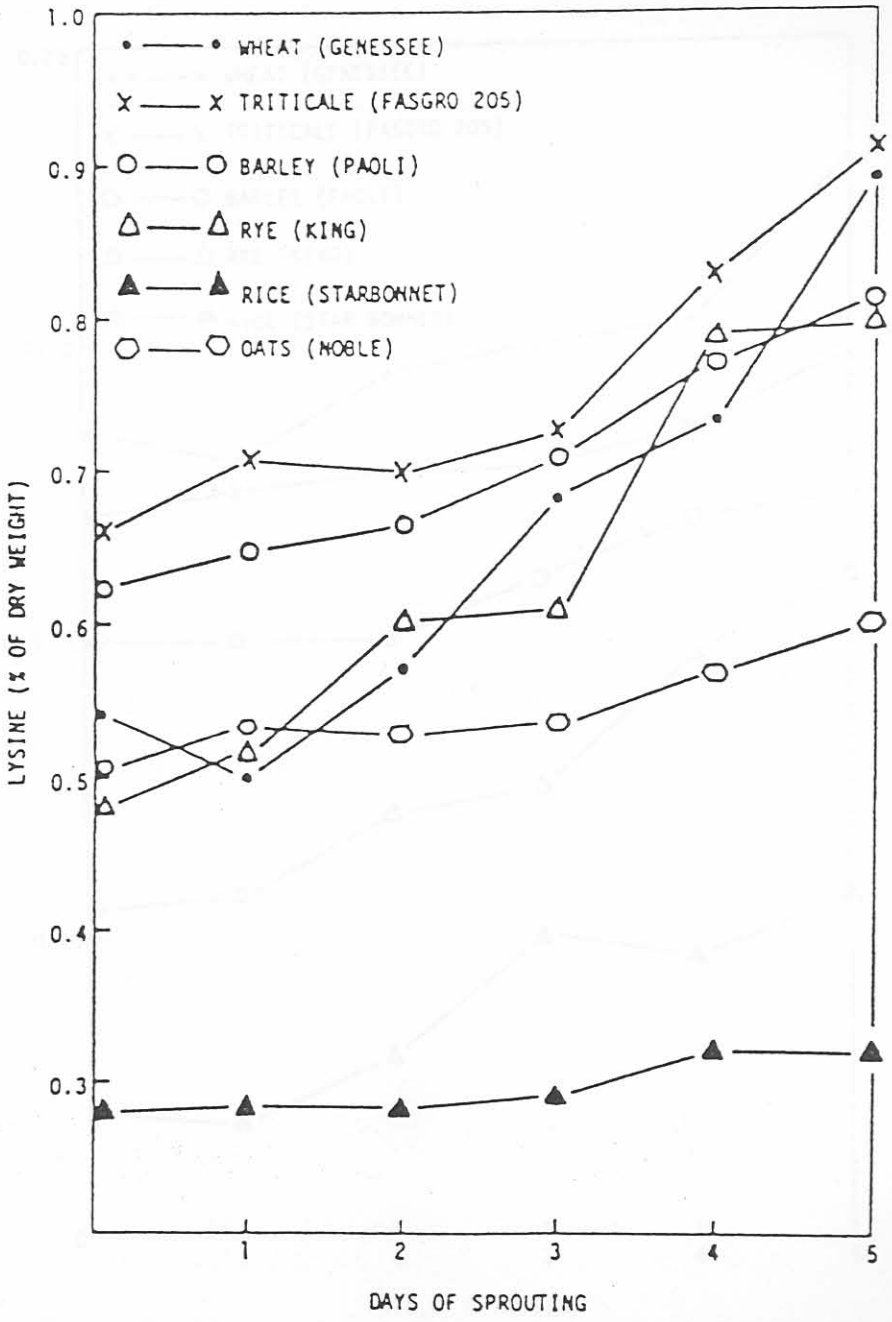

Figure 3- Changes in lysine content of cereal grains during sprouting (Dalby & Tsai, 1976)

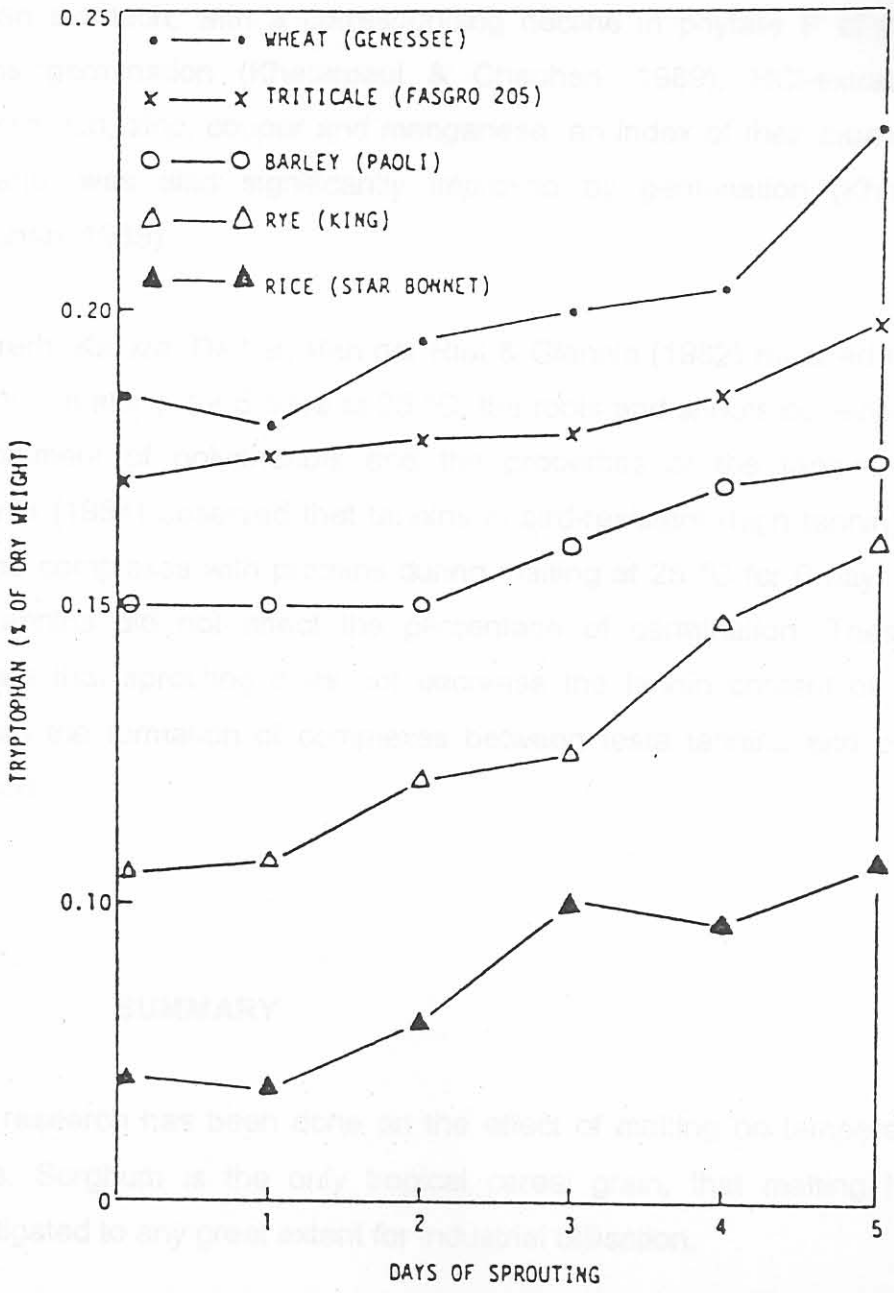

Figure 4- Changes in tryptophan content of cereal grains during sprouting (Dalby & Tsai, 1976)

Germination of finger millet, pearl and foxtail millets for 96 h at 25 °C reduced the phytate phosphorus levels (Malleshi & Desikachar, 1986b). Germination of pearl millet at 30 °C for 48 h significantly increases inorganic P, non-phytate P and phosphorus extractable in 0.03 M HCl, the concentration of acid found in human stomach, with a corresponding decline in phytate P of pearl millet grains germination (Khetarpaul & Chauhan, 1989). HCl-extractability of calcium, ion, zinc, copper and manganese, an index of their bioavalability to humans, was also significantly improved by germination (Khetarpaul & Chauhan, 1989).

McGrath, Kaluza, Daiber, Van der Riet & Glennie (1982) reported that during sorghum malting, for 5 days at 25 °C, the roots and shoots developed a large complement of polyphenols and the properties of the tannins changed. Glennie (1984) observed that tannins in bird-resistant (high tannin) sorghum formed complexes with proteins during malting at 25 °C for 6 days, although the tannins did not affect the percentage of germination. These reports indicate that sprouting does not decrease the tannin content of grain, but favours the formation of complexes between testa tannins and endosperm proteins.

2.4 SUMMARY

Most research has been done on the effect of malting on temperate cereal grains. Sorghum is the only tropical cereal grain, that malting has been investigated to any great extent for industrial utilisation.

Although some research has been done on malting conditions of millets, temperature and time of both steeping and germination, most of it concentrates on the effects of germination/sprouting on chemical composition, nutritional properties, enzymatic activities and the effects of additives on quality of malts of millets. Little research is reported on the semi- and

industrial malting of pearl millet, especially that which would suit southern African food industries. Also, there has been little research on the effect of malting on the pearl millet grain structure modification, as well as the effect of malting on the off-odour which appears in pearl millet when it is ground. It was therefore decided to devise this project to accommodate these aspects. For better understanding of the pearl millet malting process it was also thought necessary to give emphasis to the functionality of its starch, since starch is the most important functional food biopolymer in cereal grains.