REVIEW OF LITERATURE
2. REVIEW OF LITERATURE

Starch, a product of photosynthesis, is the principal food reserve polysaccharide of plants. It is one of the abundant and renewable raw materials available on Earth and provides the major share of energy in any vegetarian diet. It is widely distributed in nature, occurring in several parts of the plant, *viz.*, leaves, grains, tubers, roots, etc. Starch is functionally a very important polysaccharide that has attracted the attention of chemists, biochemists and technologists all over (Whistler *et al.*, 1984).

Millets are rich source of carbohydrate and supply most of the dietary calories to the user. Starch is the major carbohydrate and ranges from 60-70% of seeds, the non-starchy carbohydrates forming about 15% of the grain are mostly unavailable to the body (dietary fibres). Moruzzi (1931) reported 62.3% starch, 7.9% cellulose, 0.8% reducing sugar, 0.5% dextrins and 4.9% pentosan for finger millet. Wankhede *et al.* (1979) reported 59.5 - 61.2% starch, 6.2-7.2% pentosan and 1.4-1.8% cellulose for finger millet. Foxtail millet showed 56.2% starch, 5.5% pentosan and 0.7% cellulose.

Millet starches contain nearly 25-35% amylose and 65-75% amylopectin (Paramahans and Tharanathan, 1980). The unavailable carbohydrates of finger millet and pearl millet as reported by Kamath and Belavady (1980) ranged from 18.3-22.1% and 17.0-21.6% respectively as compared with 12.6-20.9% and 7.8-9.1% for wheat and rice respectively.
2.1. Changes in carbohydrate profile during germination and maturation

During the germination of cereal grains, several significant changes occur in the starch. These changes include a decrease in the starch content and an apparent increase in the amylose content (Parvathy and Sadasivam, 1982). The decrease in starch in barley during malting was about 5-10% (Greenwood and Thompson, 1961, Bathgate and Palmer, 1973) but in case of other cereals the decrease reported was generally high. The decrease in starch was 14% for wheat germinated for 5 days (Lemar and Swanson, 1976), 42% for maize germinated for 6 days (Jones and Tsai, 1977) and 54.5% for sorghum germinated for 5 days (Chavan et al., 1981). However the malting conditions such as time, temperature during germination and method adopted to estimate starch may also contribute for the varying values reported. Malting alters the properties of the starches also. Greenwood and Thompson (1959) isolated starch from barley and malted barley. The malted barley starch had a higher amylose content, higher gelatinisation temperature and smaller granules than that from native starch. The amylose from malted barley starch was smaller in molecular size and had a higher β-amylolysis limit. Similarly Bathgate and Palmer (1973) also reported that the malted barley starch had lower number of larger granules and higher amylose and gelatinisation temperature than that of native starch.

Grain development in barley (Banks et al., 1973), wheat (Matheson, 1971), and maize (Boyer et al., 1976) appears to be characterised by a steady increase in the amount of amylose synthesised, relative to the total amount of starch. In developing sweet corn, it was considered to be due both to changes in the relative numbers of the different sizes of starch granules and to changes in their amylose content (Duffus and Jennings, 1978). A similar situation exist in developing barley endosperm where the starch composition of small and large starch granules varies independently during development (Williams and
Duffus, 1977). In starch granules from mature maize (Boyer et al., 1976) and barley (Goering and De Haas, 1974) and from immature sweet corn (Duffus and Jennings, 1978) and barley (Williams and Duffus, 1977) endosperms, amylose content decreases as granule size decreases. However in wheat at maturity (Bathgate and Palmer, 1972) there was little differences in amylose content between large and small granules.

Literature survey revealed that extensive work has been carried out on the starch of major cereals like wheat, rice, maize, sorghum, barley and oats. However very limited work has been reported on the small millets.

2.2. In vitro digestion of starch by $\alpha$-amylase

Raw starch is only slowly digested by enzymes in vitro whereas cooking increases the susceptibility considerably because of the rupture and disintegration of compact crystalline granular structure (Snow and O'Dea, 1981, Faki et al., 1984, Holm et al., 1985, Lee et al., 1985). Furthermore the glucose and insulin responses in vivo were significantly greater after ingestion of cooked starches when compared with raw starches (Holm et al., 1985, Lee et al., 1985, Collings et al., 1981, Vaaler et al., 1984, Chen et al., 1983).

Consequently, degree of gelatinisation was an extremely important factor in the rate of starch hydrolysis and metabolic response. The susceptibility of starch with different degree of gelatinisation to hydrolysis by porcine pancreatic $\alpha$-amylase was reported by Holm et al. (1988). During gelatinisation inter and intra molecular hydrogen bonds are broken. This results in a loosening up of the compact granular structure and allows different degrees of swelling and absorption of water; fully hydrated starch molecules leach from the granule. Consequently, the availability of the starch granules to digestive
enzymes increases to different levels with increasing degree of starch gelatinisation. Starch hydrolysis with \( \alpha \)-amylase results in the formation of glucose, maltose, maltotriose and \( \alpha \)-limit dextrins (branched oligosaccharides with four glucose monomers or more). Therefore 75-80% hydrolysis expressed as maltose equivalents corresponds to an almost complete hydrolysis. Raw starch was hydrolysed most slowly and the susceptibility to \( \alpha \)-amylases increased with degree of starch gelatinisation. The two completely gelatinised samples (degree of gelatinisation (DG) = 100%) and starch with a DG of 96% displayed the highest availability; no significant differences was observed between these two samples.

It has long been known that the physicochemical form of starch affects both the rate and the extent of its hydrolysis by amylolytic enzymes and that there are corresponding differences in the digestibility of starch in foods. A relatively slow rate of starch hydrolysis is a characteristic of foods which provoke a low glycemic response in human subjects. Furthermore, starch which escapes digestion in the small intestine is likely to have physiological effects similar to some of the components of dietary fibre. There is a debate at present as to whether the resistant starch fraction should be included as dietary fibre or deliberately excluded by the adoption of the appropriate analytical methods (Berry, 1986). This controversy cannot be resolved at present because the behaviour of the resistant starch fraction in the intestine is not known and because the physiological effects of any starch which escapes digestion have not yet been fully investigated.

The physical form of the starch polysaccharides may undergo several transformation during processing and storage of a starch based food material. Raw granular starch occurs as a semi crystalline birefringent material which is usually processed by heating in the presence of water. If heated in an excess of water, at a characteristic
temperature known as the gelatinisation temperature, which for most starches is approximately 70°C, granular order is lost. The granules swell to many times their original size and the amylose is preferentially solubilized.

At temperatures below 100°C true molecular solution is not achieved and swollen hydrated granules consisting of mainly amylopectin remain. If the water content of the suspension is reduced the dissolution temperature of the crystallites has been estimated at approximately 190°C (Biliaderis et al., 1980). The extent of dissolution of the granular starch will therefore depend on the heat moisture treatment received during processing, from granules which are still crystalline and birefringent to fully gelatinised granules.

Upon cooling, the dispersed starch polysaccharides reassociate or retrograde. Recent work has identified the roles played by amylose and amylopectin in starch retrogradation (Miles et al., 1985b). Concentrated amylose solutions rapidly gel on cooling to room temperature, the gel arises as a result of a phase separation which produces a polymer-rich net work (Miles et al., 1985a). Subsequently some of the amylose slowly crystallizes as the double helical B-form. The gel can only be melted by heating to 160°C (Ring et al., 1987a), in this case the association can be reversed by heating to approximately 70°C. The interactions involving amylose and amylopectin are time and concentration - dependent (Miles et al., 1985 a,b). At low concentrations of solids, amylose gelation and crystallization is the dominant process. At high solids concentration amylopectin crystallization is much more significant (Orford et al., 1987). Amylose chains can also form inclusion complexes with hydrophobic guest molecules. The inclusion complex crystallizes as single helices in the V-form of amylose. The starch polysaccharides may therefore occur in quite diverse physical forms.
Porcine pancreatic $\alpha$-amylase was chosen for the *in vitro* hydrolysis of starch. A survey of the literature revealed that the levels of enzyme used in similar studies on starch varied widely. Berry (1986) used 50 units/mg polysaccharide, Ring *et al.* (1988) used 2 units and 20 units/mg polysaccharide.

The chemical forms and resistance to hydrolysis *in vitro* of raw and gelatinised starch from pea, maize and potato were measured. Raw granular starch proved very resistant to amylolysis. Only wheat starch was fully degraded after 24 h incubation with amylase (20 units/mg polysaccharide) at 37°C. In contrast, hydrolysis of freshly gelatinised starches was essentially complete within 1 h. To investigate the onset of resistance to hydrolysis after gelation, dispersions of amylose and amyllopectin were stored at 20°C prior to amylolysis. Retrogradation of amylose was rapid and the resulting material was highly resistant to amylolysis. In contrast amyllopectin underwent retrogradation more slowly and was almost completely degraded by amylases after incubation for 24 h (Ring *et al.*, 1988).

Differences in starch bioavailability among products have been attributed to several factors. One mechanism is the chemical composition of the starch. The starch in normal varieties of cereals contains only moderate levels of amylose, about 25%, whereas that in legumes may amount to 75% (starch basis) (Guilbot and Mercier, 1985). It has been suggested that the high amylose content in legumes starches (lentils and beans for examples) is responsible for the extremely low post prandial glucose and insulin responses compared with responses to most cereal products (Jenkins *et al.*, 1983).

According to Goddard *et al.* (1984) in healthy subjects, the post prandial levels of glucose and insulin following ingestion of different rice varieties increased with decreasing
amylose content (0-25% amylose). The beneficial effect of high amylose varieties was attributed to a reduced rate of enzymic digestion mainly due to the formation of complexes between amylose and lipids. Formation of such complexes is known to considerably reduce the enzymic susceptibility of the amylose component (Holm et al., 1983). Furthermore, in a recent study by Behall et al. (1989), long-term intake of a high amylose diet improved fasting triacylglycerol and cholesterol levels in healthy subjects more than a corresponding high amylopectin diet. However, available data on the impact of amylose on nutritional properties of starch are by no means clear cut.

It is known that the gelatinisation behaviour of the starch granule is affected by its amylose content. According to several reports the gelatinisation temperature of maize and pea starches is generally increased at a higher amylose content (Colonna and Mercier, 1985, Eliasson et al., 1988). Recently, it was demonstrated that a close correlation exists between the degree of starch gelatinisation and the rate of enzyme hydrolysis both in vitro and in vivo (Holm et al., 1988). Thus, a higher amylose content restricts granule swelling at conditions used during food processing, a reduced enzymic availability would be expected. A higher amylose content also increases the probability for complex formation with lipids. In addition, during heat treatment at high moisture levels, starch may retrograde so firmly that it becomes totally resistant to amylases both in vitro and in vivo (Englyst and Cummings, 1985).

Since the information about the availability of starch for digestion in vitro using porcine pancreatic α-amylase in small millets and the correlation between the amylose content and the rate of hydrolysis was scanty, the present investigation was carried out.
2.3. Scanning electron microscope (SEM) studies

Starch granules vary in size from 2 to 10 μm and may be round, oval or irregular in shape. Not all granules are simple; complex granules occur, for example in potato starch (Banks et al., 1973) and wrinkled seeded pea starch (Banks et al., 1974). In SEM the starch granules in their native form appear smooth with occasional surface indentations caused by the compression of small starch granules or protein bodies during the early stages of development in the amyloplast (Robutti et al., 1974). In wheat and barley starches the presence of equatorial groove, particularly around the big lenticular granules is conspicuous (Evers and McDermott, 1970). This is not merely indentation but represents a manifestation of a medium plane of weakness, wherein the polarizing crosses intersect in the polarized light. The granule appears thin at this plane, and in vitro condition the enzyme action and penetration starts from the equatorial region. The precise nature of the genetic and biochemical factors which control the number, size, shape and composition of starch granules remain a mystery.

Finger millet starch granules exhibited polygonal rhombic shape whereas pearl millet starch granules were mostly round and spherical. The striking feature of finger millet granules is the greater non-uniformity in their size and shape, where size of the granules ranged from 4 to 18 μm and majority of granules (about 42%) were within 8-13μm. Pearl millet starch granules were generally bigger than that of finger millet and nearly 72% starch granules of pearl millet ranged from 8-13μm and only 20% granules were in 4-7μm ranges (Malleshi et al., 1986).

Proso millet starch granules have a bimodal distribution with two basic shapes and sizes, small spherical and large polygonal. Many large polygonal granules show
indentations due to the dense packaging of the endosperm. Starch granule sizes ranged from 1.8 to 13.5 μm; mean diameters varying from approximately 4 to 5 μm with slight variation among the cultivars (Yanez et al., 1991). Proso starch granules resemble those of rice which have a mean granule size ranging from 4 to 6 μm (Juliano, 1984).

2.4. Brabender viscoamylogram

Fukuba (1954) and Fukuba and Yamamoto (1954) were the first to study the Brabender Viscograms of rice flour. They found that Indica rice flour showed higher viscosity than Japonica rice, and that rices having higher amylose gave higher cooling curves. Shortly afterwards, Halick and Kelly (1959) made a detailed study of the pasting curves of a large number of rice varieties. Since then this test has been extensively used by researchers to assess rice quality in various laboratories.

Halick and Kelly (1959) noted that long grain varieties with higher amylose, usually gave a positive set back and a lower peak viscosity. Kurasawa et al. (1962, 1969) observed that sticky rice (low in amylose) preferred by Japanese generally showed a higher peak viscosity and breakdown and lower set back as compared to less sticky rice (high in amylose). Similar observations were made by Tani et al. (1969), Chikubu (1967), Hampel (1965, 1967), Beachell and Stansel (1963), Juliano et al. (1964a, 1964b), Juliano and Perdon (1975) and Juliano and Pascaul (1980).

Even for rices of similar amylose content, the viscosity parameters appeared to be provided good indication of their texture (Perez and Juliano, 1979, Merca and Juliano, 1981). This was especially true of waxy rice where amylose was absent (Juliano et al., 1969, Antonio and Juliano, 1974, Perez et al., 1979, Kongseree, 1979). Brabender
viscoamylograms of millet flour indicated that the gelatinisation temperature of millet starch was around 73-77°C (Haidmani and Malleshi, 1993). Very little information is available regarding the viscoogram studies on small millet starch.

2.5. Chain length of amylose and amylopectin

Starch, the major storage polysaccharide of higher plants, is a polymeric mixture of essentially linear (amylose) and branched (amylopectin) α-D-glucan molecules. Starch is deposited in the form of granules, partially crystalline, whose morphology, chemical composition and supermolecular structure are characteristics of each particular plant species. Starch owes much of its functionality to the physical organisation of these macromolecules into the granular structure (French, 1984).

Takeda et al. (1986a) reported the average chain length of amyloses from rice as 250-370 glucose units. Takeda et al. (1987) studied the chain length of 9 amyloses from cereals, seeds, roots and tubers. The degree of polymerization of these amyloses ranged from 960 (corn) to 3280 (sweet potato) and the cereal amyloses appear to be smaller molecules than other amyloses. The average chain length of amylose ranged from 270 glucose units to 525 glucose units. The average chain length of com was 353 glucose units, rice 320, wheat 270, chestnut 375, kuzer 310, Nagaimo 525, lily 475, tapioca 340, sweet potato 335 glucose units. The amylomaize amyloses had lower chain length than normal maize amylose and those of other sources (Takeda et al., 1989).

Amylopectin is one of the biggest molecules in nature; it is the principal component in the majority of starches and perhaps the most important in terms of their functional properties (Manners, 1989). The distribution of chain lengths of the
Amylopectins from 20 species were characterized by Hizukuri (1985) and the average chain length of amylopectin were in the range of 23-44 glucose units. Thayumanavan (1987) reported the chain length of amylopectin of rice which varied from 21 to 26 glucose units. Salomonsson and Sundberg (1994) reported that the amylopectin of the high amylose starches had longer chains than those of the normal or waxy starches. The chain length of amylopectin of potato starch was 23.7 (Takeda et al., 1986) and chain length for lily amylopectin was 23.6 (Suzuki et al., 1981). Jane and Chen (1992) reported that high amylose corn amylopectin had the longest chain length per branch.

2.6. Resistant starch (RS)

RS is a fraction of starch not digested in the small intestine. It may, however, be (partially) fermented in the large bowel by the microflora (Englyst and Macfarlane, 1986). Resistant starch is measured in vitro as the starch that is resistant to alpha amylase plus pullulanase digestion (Cummings et al., 1992). In cooked cereals, in vitro resistant starch has been shown to be essentially retrograded amylose having a degree of polymerization (DP) of 55-65 glucose unit.

Table 1. Classification of resistant starches (Baghurst et al., 1993).

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<th>Type of starch</th>
<th>Example of occurrence</th>
<th>Probable digestion in the small intestine</th>
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<tbody>
<tr>
<td>Rapidly digestible starch (RDS)</td>
<td>Freshly cooked starchy foods</td>
<td>Rapid</td>
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<tr>
<td>Slowly digestible starch (SDS)</td>
<td>Most raw cereals</td>
<td>Slow but complete</td>
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<tr>
<td>Resistant starch</td>
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<tr>
<td>1) Physically indigestible starch</td>
<td>Partly milled</td>
<td>Resistant</td>
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Formation of enzyme resistant starch (RS) during autoclaving and cooling was investigated in starches from wheat, maize, potato, pea, waxy maize and amylo maize. Amylose content and yield of RS were positively correlated. The highest yield (21.3%) was obtained from amylo maize starch (70% amylose). Formation of RS in amylo maize starch was affected by the starch/water ratio, autoclaving temperature and number of autoclaving-cooling cycles (Sievert and Pomranz, 1989).

Schoch and French (1947) pointed out that amylopectin had a major effect on bread-staling (retrogradation), and suggested that linear side chains of amylopectin associated gradually and caused firming. Amylose has less effect because it rapidly associates immediately after baked bread cools. Other researchers have confirmed that during the storage of starch based foods, amylose crystallizes rapidly and amylopectin crystallizes slowly (Miles et al., 1985a, Orford et al., 1987, Ring et al., 1987, Russel, 1987). The melting temperatures for retrograded gel were 55°C for amylopectin crystallites and 130°C for amylose crystallites (Eberstein et al., 1980).

Limited work has been reported relating starch molecular characteristics and retrogradation behaviour. Whistler and Johnson (1948) found there was an optimum chain length (undetermined) for amylose retrogradation; Gidley et al. (1986) found the minimum chain length required for retrogradation was 8 or 9 glucose units. Both results, however, were obtained using starch solutions (0.5 - 3.0%) rather than gel systems. Sterling (1978)
reported that β-amylase treated amylopectin (external branches reduced to 2-3 glucose units) retrograded less readily than native amylopectin.

Starch that resists breakdown in the small intestine will pass into the large intestine where they act in a similar manner to the unabsorbed non-starch polysaccharides of dietary fibre. Some non-starch polysaccharides reduce whole-gut transit time and increase stool weight and there are various mechanisms proposed to explain these effects. One of these reveals that the carbohydrates act as substrate to the bacteria, stimulating bacterial growth and increasing bacterial cell mass (Stephen and Cummings, 1980) and generating fermentation products such as shortchain fatty acids and gases which may affect colonic mobility and secretion (Fleming et al., 1983).

The products formed during colonic fermentation are mainly short chain organic acids particularly acetic, propionic and butyric acids and hydrogen. Several beneficial physiological effects have been associated with the formation and metabolism of these acids (Chen et al., 1984; Anon., 1988). Fermentation of starch preferably yields butyrate which was known to be the major energy source for the colonic mucosal cells (Englyst and Cummings, 1987). This has focussed interest on the possibility that undigested starch has a preventive role in the genesis of colonic diseases eg. adenoma (Thornton et al., 1985), carcinoma (Anon., 1988) and ulcerative colities (Roediger, 1980). The mechanisms of incomplete digestion and absorption of starch are not fully elucidated but important determinants are food structure, the type of starch and the type and extent of food processing (Bjorck et al., 1986, 1987, 1989; Englyst and Cummings, 1986; Jenkins et al., 1987a; Schweizer et al., 1990; Wursch, 1989).
Feeding of raw starch (Mazur et al., 1990) or retrograded amylose (prepared by gelatinisation of high amylose corn starch) (Faulks et al., 1989) leads to increased faecal mass. In animals fed with raw or retrograded starch, faecal carbohydrate and shortchain fatty acid concentrations are also increased. This outcome is consistent with enhanced fermentation (Faulks et al., 1989, Goodlad and Mathers, 1992, Levrat et al., 1991). Furthermore, studies in pigs with Cecal fistulae reveal that legumes increase large-bowel digesta and shortchain fatty acids (Fleming et al., 1989).

With respect to faecal bulking, the contribution of starch may be much greater than that of non-starch polysaccharides simply because more starch is eaten than other carbohydrates. This suggestion is of considerable importance because faecal bulk appears to be negatively related to colon cancer risk (Cummings et al., 1992). Faulks et al. (1989) reported that, in the rat there are significant differences in the utilisation of resistant starches from different sources.

Toshinao et al. (1994) reported that diet rich in amylose effectively reduced the lipogenic enzyme activities in both adipose tissue and liver as compared with diet containing the same amount of regular starch. Delayed digestion and absorption of starch rich in amylose might be responsible for the reduced lipogenic enzyme activities. Further they demonstrated that the decrease of lipogenic enzyme activities found in the animals fed with the high amylose diet might lead to the changes in blood and adipocyte lipid contents. First, the animals fed the high amylose diet exhibited a reduced serum concentration of triacylglycerols. This result was in accordance with the report which showed that the volunteers who consumed the high-amylose corn starch for 5 weeks exhibited significantly reduced blood triacylglycerol levels (Behall et al., 1989). Secondly feeding the high amylose diet led to a decrease in both epididymal and mesentory adipose tissue weights by
Gee et al. (1991) reported that retrograded amylose prepared from high amylose corn starch was partially degraded in the alimentary tract of rats, but it contributes significantly to faecal bulk.

2.7. Glycemic index

Until recently, starch was believed to be 100% digested in the small intestine independent of the source, type and preparation of the starch. However within the past 10 years it was found that despite the fact that pancreatic A-amylase is present in the gut in ample amounts, a fraction of the ingested starch passes undigested to the large bowel which has been named as resistant starch. The amount of RS present in starch-rich foods depend on several factors ie. the source, ripeness, processing, preparation and storage of the foods. It was shown that starch from white bread, porridge oats and corn flakes were almost completely digested in the small intestine (Englyst and Cummings, 1985), whereas native starch from banana or uncooked potato was highly resistant to hydrolysis in vitro (Fuwa et al., 1980) and in vivo (Englyst and Cummings, 1987).

The potential use of RS as a weight reducing agent may also be of interest because the energy value of 1 g RS, including the contribution from fermentation products, has been estimated to be only 9.0 - 9.8 kJ g⁻¹ ie. half the value of digestible starch (Mathers, 1991).

Crapo et al. (1981) studied the acute effect of oral ingestion of dextrose, rice, potato, corn and bread on post prandial serum glucose, insulin and glucagon responses in 20 non-insulin dependent diabetes mellitus (NIDDM) patients with fasting hyperglycemia. The data demonstrate that (1) dextrose and potato elicited similar post prandial serum
glucose responses whereas rice and corn elicited lower responses; while bread intermediate. (2) post prandial insulin responses were relatively flat but rice ingestion led to significantly lower insulin responses than did potato; (3) urinary glucose excretion during the 3 h after carbohydrate ingestion was greater following dextrose and least after rice and corn. In conclusion, there was a range in the magnitude of post prandial hyperglycemia after ingestion of different complex carbohydrates in diabetic patients with fasting hyperglycemia and emphasis on the use of the less hyperglycemic starches could be of therapeutic value in controlling hyperglycemia.

Diabetic patients have been advised recently to increase their carbohydrate consumption in order to decrease fat intake and hopefully the risk of cardiovascular disease. Little advise has been given as to which specific foods should be eaten to achieve this. However common starchy foods produce different glycemic responses (Crapo et al., 1976). The glycemic index (GI) was proposed as a method of ranking foods on the basis of the incremental blood glucose responses, they produce for a given amount of carbohydrate (Jenkins et al., 1981). It was suggested that low GI starch foods may be beneficial in diabetes (Crapo, 1983; Jenkins et al., 1984). Glycemic index of some foods are given in Table 2.

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<th>Table 2. Glycemic index of some foods (Jenkins et al., 1981)</th>
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<tr>
<td>Food</td>
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<td>--------------------------------</td>
</tr>
<tr>
<td>Glucose</td>
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<tr>
<td>White rice</td>
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<tr>
<td>Whole wheat bread</td>
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<tr>
<td>White bread</td>
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<td>Corn flakes</td>
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The systematic classification of foods according to their glycemic responses was first undertaken by Otto and Niklas (1980) who after testing individual foods, allowed their incorporation into the diabetic diet in amounts inversely proportional to their glycemic responses to keep the glycemic response of the diet constant. The glycemic index was developed independently as a classification of the glycemic effect of foods to supplement information about chemical composition given in food tables (Jenkins et al., 1981). It was reasoned that knowledge of the glycemic effect of individual foods might be of use in understanding the physiological effects of whole diets. Unexpected differences between the GI values of different foods helped to highlight the importance of food factors not given in food tables such as food form, particle size, the nature of the starch, food processing and antinutrients, which may have large effects on the physiologic properties of foods.

The *in vitro* resistant starch values for rice samples used in earlier collaborative studies were correlated negatively with glycemic index or insulin response.
Apparent amylose content, gelatinisation temperature and processing were related to lower glycemic responses (Eggum et al., 1993a).

Extrusion of rice to noodles can decrease the rate of \textit{in vitro} digestibility and glycemic responses of normal and diabetic subjects. This may be related to retrogradation of gelatinised high amylose rice starch during extrusion as indicated by the high amylograph set back and consistency of milled rice compared to rice noodles upon storage. The greater reduction in digestibility in rice noodles versus milled rice further suggest that the starch in rice noodles were more prone to retrogradation.

High amylose rice noodles may therefore be considered as lower glycemic index food and can therefore add variety in planning diets not only for people with chronic diseases such as diabetes, hyperlipidemia and obesity but also normal individuals (Panlasigui et al., 1990).

Rice varieties with similar amylose content can differ in starch digestibility and glycemic response in humans due to physicochemical properties, such as gelatinisation temperature, minimum cooking time, amylograph consistency and volume expansion upon cooking (Panlasigui et al., 1991).

Glycemic indexes of cooked rice and various Thai noodles were recently determined by Komindr \textit{et al.} (1987) in non-insulin dependent diabetics. Earlier workers (Goddard \textit{et al.}, 1984 and Jenkins \textit{et al.}, 1981) showed that glycemic index of cooked milled rice correlates negatively with amylose content. The correspondence of \textit{in vitro} starch digestibility with glycemic index was affected by homogenization
(Crapo and Henry, 1988 and Berry et al., 1988) and starch species (Jenkins et al., 1981 and Thorne et al., 1985) in addition to varietal differences (Behall et al., 1988, Goddard et al., 1984, Juliano and Goddard, 1986) and processing (Jenkins et al. 1981 and Wolever et al., 1986b). Blending was reported to mask the differences in glycemic index between rice and potato (Crapo and Henry, 1988). Since parboiled rice has a lower glycemic index than raw rice (Wolever et al., 1986b) and since while spaghetti also has a lower glycemic index compared with white bread (Jenkins et al., 1981), the starch properties of these various Thai foods were determined at the cereal chemistry department of IRRI to verify starch properties correlated with glycemic index. The new in vitro starch digestibility method of Kainuma et al. (1981) for degree of gelatinisation and retrogradation was used on the food slurries to index the starch digestibility in these Thai foods.

Juliano et al. (1989) reported that glycemic index responses of two cooked rices and six types of cooked noodles consumed by eight non-insulin dependant diabetics correlated positively with in vitro starch digestibility of food slurry and negatively with amylose content of the food. Glutinous (waxy) rice has the highest values and mung bean noodles the lowest.

Chewing can affect the amount of starch escaping digestion in vitro (ie. RS). The more time a starch-containing food was chewed the less starch escaped digestion in in vitro assay system (Muir and O'Dea, 1993); Read et al. (1986) reported that chewing increases the glycemic index of food. Chewing helps in the breakdown of the physical structure of the food, enabling greater for access of digestive enzymes to the starch. This effect seems to be greater for some foods eg. whole boiled long - grain white rice than others (eg. roasted chickpeas), which suggests that the food form was an important factor in determining the amount of RS in whole boiled rice, whereas it does not affect amounts
of RS in roasted chickpeas to the same extent. There was a marked differences in the amount of RS between boiled and roasted chickpeas, suggesting that the industrial processing of roasted chickpeas involving high temperature, dry roasting may affect amounts of RS. Indeed it was known that formation of retrograded amylose was dependent on temperature and moisture content (Berry, 1986). Corn flakes are a commercially processed breakfast cereal. The *in vitro* assay showed approximately 6.5% (dry weight) of the starch in corn flakes escaped digestion. Grinding and chewing both had significant effect on the amount of RS. It seems likely that RS may contribute significantly to the fermentable carbohydrate in this food because corn flakes are low in non-starch polysaccharides (0.9% dry weight) (Cummings and Englyst, 1987).

The amount of RS produced during the processing of starchy foods will be controlled by a complex of factors such as water content, pH, heating temperature and time, cooling temperature and time, number of heating / cooling cycles, freezing and drying (Berry, 1986).

The normal human diet contains highly refined starchy foods and therefore, the amount of carbohydrate entering the large intestine may be small. If, as is likely, it can be shown that an active fermentation in the colon is conducive to good health, then there is need to increase the amount of carbohydrate that enters the colon. This may be achieved by an increased consumption of non-starch polysaccharide and/or resistant starch.

The level of RS in food products could be increased by relatively minor changes in processing techniques. For example, the present levels of 1% RS in white bread and 3% RS in cornflakes might be raised to 5-10%. Further, the selective use of high amylose products would also control the levels of RS in foods (Englyst and Macfarlane, 1986).
Literature survey revealed that extensive work has been carried out on the resistant starch content of major cereals like rice and wheat. No work has been reported on the resistant starch and glycemic index of small millets. Hence, it was also aimed to find out the glycemic index of native and treated starch prepared from small millets in normal human volunteers and NIDDM (Non-insulin dependent diabetes mellitus) patients.