PROCESSING OF PEARL MILLET FOR ITS MORE EFFECTIVE UTILIZATION

By

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IN

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Dedicated to

My Parents

CERTIFICATE I

This is to certify that the thesis entitled "Processing of pearl millet for its more effective utilisation" submitted for the degree of Ph.D., in the subject of Foods and Nutrition to the Haryana Agricultural University, Hisar is a bonafide research work carried out by Ashima Jain Aggarwal under my supervision and no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

8/10/92

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CERTIFICATE II

This is to certify that the thesis entitled "Processing of pearl millet for its more effective utilisation" submitted by Ashima Jain Aggarwal to the CCS Haryana Agricultural University, in partial fulfilment of the requirements for the degree of Ph.D., in the subject of Foods and Nutrition, has been approved by the student's Advisory Committee after an Oral Examination on the same, in collaboration with an External Examiner.

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INTRODUCTION

Pearl millet (Pennisetum typhoides) is grown extensively in the dry areas of western and southern India and along the periphery of Sahara, where it is used as a food for an estimated 400 million people. Pearl millet is one of the most important cereals ranking sixth in the world's cereal production. Pearl millet often produces a greater quality of grains than other cereals under conditions of less fertile soil, intensive heat and limited rainfall.

Pearl millet is utilised mainly as food grain for human consumption. The coarse grain is looked down upon as poor man's food limiting users to villages. Increasing availability of finer cereals, wheat and rice, has resulted a shift in the foodpreferences away from pearl millet among rural masses. Marketing environment is hardly favourable as the grain is not covered by procurement price support, subsidies, or public distribution system. During favourable rainfall when there is a bumper crop, the markets are flooded with surplus grain and there are not many buyers available. Thus, pearl millet grain is highly underutilised and fetches poor returns to the growers.

It has a higher protein content than do other cereals grown under similar conditions (Hoseney et al., 1981) and a fat content upto 8 per cent (Lai and Varriano-Marston, 1980; Rooney, 1978).

No doubt pearl millet has a relatively better mineral profile but owing to certain inherent factors bioavailability of these minerals to human system is low (Mahajan, 1986). More than half of the phosphorus is present in phytate form which is not available to human system (Daniels and Fisher, 1981). Besides, dietary phytate is known to render minerals, especially divalent cations, unavailable as well as to inhibit the proteolytic and amylolytic enzymes (Sutardi and Buckle, 1985). The formation of a tertiary protein-mineral-phytate complex is believed to inhibit the enzymatic degradation of protein and results in lower digestibility of protein (Serraino et al., 1985; Knuckles et al., 1985). In the presence of phytate, starch digestibility is also significantly reduced (Yoon et al.,1983).

Inspite of greater availability, low cost and comparatively good nutritional value, use of pearl millet in food industry is very low as compared to that of wheat and maize. The main reason is its poor keeping quality. Pearl millet flour develops unpleasant odour and often bitter taste when stored for more than 7-10 days (Kaced et al., 1984). Pearl millet can be stored for long periods without dramatic quality changes if the kernels remain intact. But once the grain is subjected to grinding, the meal quality rapidly deteriorates. This is because of its higher fat content and presence of higher proportions of usaturated fatty acids (Rooney, 1978). Both hydrolytic and oxidative rancidities occur in pearl millet flour resulting in release of free fatty acids and formation of peroxides (Carnovale and Quaglia, 1973). The solution to the storage

instability of milled pearl millet lies, therefore, in developing milling processes that remove the major lipid containing portions.

Through wet milling it has been possible to separate germ, bran and ensosperm (17.4, 7.5 and 75 per cent of the grain, respectively) Parts of the millet grain (Abdelrahman et al., 1984). Most of the fat (about 87 per cent) of the grain resides in the germ and the latter contains about 32 per cent fat on dry weight basis. But unfortunately this process produces an awful odour and the endosperm grits are not acceptable as human food. If by a suitable process, the germ and endosperm are separated, the pearl millet grain can prove to be a potential source of edible oil. The fatty acid profile of pearl millet oil is almost similar to that of fat from corn and other cereals which affirms its suitability for human consumption. As it is likely, the lipoxygenase activity gone with the germ the endosperm can be made to good quality flour having a long storage life. Besides, this, milling may also increase the availability of nutrients by reducing antinutrient content as the antinutrients, concentrated in the outer covering layers of grain, are removed by milling. New products from endosporm grits can be developed and commercialized.

With these perspectives, the present study was carried out with the following objectives :

i) To standardise the process of separating germ, endosperm and bran from whole pearl millet grains and to determine the nutritional value of these components.

ii) To explore the possibility of utilising the germ and bran as a source of edible oil.

iii) To develop methods of utilisation of the separated endosperm for human nutrition.

REVIEW OF LITERATURE

Pearl millet is one of the coarse grains which have limited used as human food. Its utilization can be enhanced only if the different components are seperated and put to different uses. Literature on the topic has been reviewed under following subheads.

2.1 Nutritents

2.2 Antinutrients

2.3 Milling

2.4 Storability

2.5 Food products

2.1 Nutrients

Pearl millet kernels are generally tear-shaped. Kernel shape, size and appearance vary significantly among pearl millet varieties, and also with in a sample, kernels vary significantly in size and shape.

A scanning electron micrograph of a fractured kernel shows that the germ is large in proportion to the rest of the kernel. The kernel contains translucent and opaque endosperm portions, the ratios of which vary considerably among cultivars. The pericarp has three layers: the epicarp, the mesocarp, and the endocarp (Bedi et al., 1976a' Sullins and Rooney, 1977). The aleurone cells are one layer thick and appear to be firmly attached to the pericarp. The translucent endosperm is devoid of air spaces and contains polygonal starch granules embedded in a protein matrix.

The information on major nutrient contents of pearl millet grain has been reviewed and furnished in the tabular form (Table 2.1).

Table 2.1: Protein, fat and ash contents (g/100g) of pearl millet grain

Sr.No.	Protein	Fat	Ash	References
1.	12.8 to 13.2	4.1 to 4.3	5.7 to 7.1	Salpico and Yambo(1968)
2.	7.9 to 20.1	4.6 to 6.4	2.0 to 3.2	Sawhney and Naik (1969)
3.	9.2 to 16.1	4.5	-	Burton et al. (1972)
4.	8.42 to 14.5	5.24 to 6.28	1.82 to 2.47	Singh and Popli (1975)
5.	11.3 to 19.6	3.0 to 4.6	1.5 to 2.6	Uprety and Austin (1972)
6.	12.5	5.6	2.8	Desikachar (1977)
7.	8.9	6.9	2.1	Perten (1977)
8.	10.4 to 13.2	6.03 to 8.05	1.8 to 2.48	Chaudhary and Kapoor (1980)
9.	10.6	5.6	1.7	Batra (1985)
10.	10.5 to 14.8	8.32 to 10.4	-	Chauhan et al. (1986)
11.	9.90	6.42	2.0	Khetarpaul (1980)

Abdelrahman et al. (1984) studied the anatomical parts of pearl millet and found that large, medium and small kernels had endosperm 76.2 , 75.0 and 73.8 weight per cent respectively; bran contents were 7.17, 7.52 and 10.64 weight per cent, respectively; germ contents were 16.62, 17.40 and 15.47 weight per cent respectively. Small kernels with thick and thin pericarp had 2.31 and 9.31 weight per cent bran, respectively.

Varriano-Marston and Hoseney (1980) reported that major lipid containing portions of pearl millet grain were germ and covering layers. According to Abdelrahman (1984), protein, fat and ash contents of kernels were:

whole grain 13.3, 6.26 and 1.68; endosperm 10.88, 0.53 and 0.32; germ 24.52, 32.18 and 7.18; and bran 17.07, 5.04 and 3.20%, respectively. It was further reported that endosperm contained 59..5% of total grain protein, 6.24% of the fat and 13.89% of the ash; germ contained 31.20, 87.82 and 72.205, respectively.

Reichert and Youngs (1977) studied the chemical composition o Nigerian millet dehulled with a laboratory barley pearler village scale abrasive and attrition type mills and compared it with grains dehulled with the traditional mortar and pestle. Their results showed that mechanically dehulled grains contained 31-51% less oil and ash and 9-18% less protein than the whole grains at 75% extraction rate. Traditionally dehulled grains contained 7-21% less oil and ash and 8-9% less protein than whole grains at 75% extraction rate. Abdelrahman et al. (1983) studied the effect of different tempering conditions on total yield and fat content of each fraction produced by each set of tempering conditions using corrugated roller mills. Samples with initial moisture content of 9.55% were tempered to 16, 18 and 230% moisture levels for 6, 12 and 18 h. They found that increasing the moisture content of grain increased the amount of germ recovered and consequently increased the amount of fat separated in the germ for all three comparing times used. The fat content of germ varied from 15.76 to 50.73% of total fat at different tempering moisture levels and periods. The minimum was at 16% moisture level for 18 h tempering period and maximum at 20% moisture level for 6 h tempering time.

Dewit and Schweigart (1970) showed that milled grain of pearl millet contained 13.7% protein and 4.4% fat as compared to 16.8% protein and 5.7% of fat of whole grain. Adrian et al. (1975) reported the chemical composition of the pearl millet fractions obtained by SEPIAL (Societe alimentaine d' etudes et d' exploitation de procedes pour l industrie milling process). The results showed that protein rich fraction contained 4.1% ash and 14.2% lipid whereas decorticated grain has 1.3% ash (lipids not reported). Bookwalter et al. (1987) also reported the higher protein, fat and ash content of germ than pearl millet whole grain. Saunders (1990) found 12-16% protein, 16-22% fat and 7-10% ash in rice bran.

Kurien et al. (1967) stated that refined finger millet flour, prepared by wet processing was a poor source of protein, calcium and phosphorus, as large quantity of nutrients was being discarded in water.

From the limited evidence available, glucose appears to be the principal free sugar in the pearl millet. Bhatia et al. (1972) reported 4.6 and 5.4% water soluble sugars in two samples. Uprety and Austin (1972) reported total sugar content of 2.01 to 2.70 per cent. Pearl millet sugars are composed of glucose, fructose, sucrose and maltose along with higher oligosaccharides. Total carbohydrates in pearl millet ranged from 65.4 to 71.2 per cent and starch constituted 56.3 to 63.7 per cent (Singh and Popli, 1973). Lineback and Ponpipom (1977) found 10 mg of glucose per gram of flour in one sample. Subramanian et al. (1981) found values of 2.6 - 2.78% for 9 cultivars.

Starch content of pearl millet ranges from 56 to 65% of the grain (Freeman and Bocan, 1973; Sheorain and Wagle, 1973; Bailey et al., 1979). Badi et al. (1976b) reported 17% in one sample of pearl millet. Beleia et al. (1980) found amylose contents of 20-22% for five cultivars. Mahajan (1986) reported that total soluble sugars, reducing sugars, non-reducing sugars and starch content of pearl millet were 2.5, 0.30, 2.20 and 55 g/100 g, respectively while Khetarpaul (1988) reported the contents of 4.52, 1.22, 3.30 and 63.3 g/100 g, respectively.

Panwal and Panwar (1989) found that 24 h soaking of pearl millet in 0.2 N HCl decreased the starch content of pearl millet from 60.1 to 58%.

According to Osman et al. (1988), heat, maize and rice germ contained reducing sugars 1.58, 0.46 and 0.64%, non-reducing sugars 15.99, 5.75 and 11.7%, total carbohydrates 29.75, 41.79 and 51.2%, respectively. Amarjeet et al. (1990) revealed that debranning of wheat resulted in decresed level of total and non-reducing sugars to a lesser extent as compared to other nutrients. Starch and reducing sugars, on the other hand, increased after debranning.

The information on mineral contents of pearl millet grain mg/100 g has been reviewed and given in the tabular form (Table 2.2).

Calcium, phosphorus (including phytin phosphorus) and iron contents may be significantly reduced by removal of the outer pericarp, pericarp, though the highest concentration of phytate occurs in the

Table 2.2: Mineral composition of pearl millet grain (mg/100g)

Sr.	Calcium	Phosphorus	Iron	Zinc	Reference
1.	60	310	8	-	Rama Rao et al.(1953)
2.	55	358	-	-	Kurien et al.(1961)
3.	7-117	631-1353	2.1-11.7	0.10-3.8	Shah and Mehta,1959; Carr, 1961; Goswami et al.,1969a, 1969b; Burton et al.,1972; Varriano - Marton and Hoseney, 1980.
4.	35-62	245-348	2.1-5.2	-	Uprety and Austin(1972)
5.	40	-	2.8	2.5	Awadalla & Slump (1974)
6.	3-62	248-950	1.1-38.0	-	Hulse et al. (1980)
7.	69-83	274-302	-	-	Dhillon et al.(1982)
8.	25-90	-	5.48-7.35	1.90-2.50	Kumar and Kapoor (1984)
9.	52-65	300-390	-	-	Chauhan et al.(1986)
10.	48.5	302	16	2.7	Mahajan (1986)

germ (Hulse et al., 1980). Varriano-Marston and Hoseney (1980) repored high levels of silicon and potassium in the covering layers (including the aleurone) of pearl millet. Most of the phosphorus was in the germ and high levels of iron were in the germ and covering layers. In general, the endosperm was low in minerals; the predominant elements detected were sulfur, potassium and iron.

Kurien and Desikachar (1966) found that milling the finger millet after adding 5% moisture for 30 min gave the husk fractions rich in calcium and phosphorus. According to Awadalla and Slump (1974) decorticated Egyptian millet contained only 10.0, 1.3 and 0.8 mg/100 g of calcium, iron and zinc, respectively as compared to 4.0, 2.8 and 2.5 mg/100 g of calcium, iron and zinc in whole pearl millet. Desikachar (1977) reported that bran of pearl millet contained 1450 mg/100 g phosphorus. Pawar and Parlikar (1990) found that phosphorus in pearl millet decreased from 3.16 to 1.79 mg/g after dehulling and soaking in 0.2N HCl.

Several studies have indicated that solubility of minerals in foodstuffs subjected to in vitro gastric or gastro-intestinal digestion is indicative of their bioavailability from these foodstuffs (Rao and Prabhavathi, 1978; Lock and Bender, 1980; Millet et al., 1981; Schricker et al., 1982; Schwartz et al., 1982; Wien and Schwartz, 1983; Wien and Schwartz, 1985).

Chompreeda and Fields (1984) stated that extractable minerals are those which are soluble in 0.03N HCl, the concentration of HCl found in stomach of adult. They incubated the food samples

in a waterbath set at 37°C for 3 h with constant stirring and after filtering through an ashless filter paper, analysed the filtrate for minerals. The HCl-extractable minerals presented an index of their availability from the foods.

Khetarpaul (1988) reported HCl- extractability of 36.0, 32.5, 19.4, 42.2, 35.2 and 52.8 per cent for calcium, phosphorus, iron, zinc, manganese in pearl millett, respectively.

Availability of calcium from whole meal, refined flour and composite flour of finger millet was studied by Kurien (1967) and his findings showed that average intakes of calcium were similar from all these diets but average retention from whole meal was 47% as compared to 68% and 74% from refined and composite flour, respectively. It was further reported that calcium in refined and composite flours was derived solely from endosperm and may be more readily available than calcium from husk.

Fatty acid profile of pearl millet oil is almost similar to that of fat from other cereal grains, except that pearl millet oil has higher levels of palmitic acid and stearic acid. Fatty acids in the free lipids were oleic (53.8%), linoleic (34.9%), palmitic (10.8%), stearic (0.28%) and myristic (0.20%) (Agarwal and Sinha, 1964). Jellum and Powell (1971) found linoleic (40.3-51.7%), oleic (20.2-30.6%), and palmitic (17.7-25.0%). They also reported average values of 3.69% for linoleic acid, 3.9% for stearic acid, 0.64% for arachidic acid and 0.55% for palmitoleic acid. Linoleic, oleic, palmitic and stearic acids have been reported to be the major acids of pearl millet fat (Jellum and Powell, 1971; Rooney, 1978; Hoseney et al., 1981; Chauhan et al., 1986).

Belova et al. (1970) found that major fatty acids were palmitic, stearic, oleic, linoleic, linolenic and genoloinic acid with 1 per cent myristic acid, palmitoleic acid and saturated C_{16} and C_{20} acids. Most of the fatty acids present in millet lipids were unsaturated (78.4 to 82.1 per cent) while the proportion of saturated acid amount to 17.9 to 21.6 per cent. Lai and Varriano-Marston (1980) reported that unsaturated fatty acids averaged 70.3% of the free and 51.7% of the bound lipid fraction. Linoleic, oleic and palmitic acids were the principal fatty acids in both free and bound lipids. Trace levels of myristic and behenic acids were found in free lipids. Chaudhary (1981) also reported that the linoleic, oleic and palmitic acids were the principal acids in free lipids. The saturated fatty acids varied from 22.3 to 28.6 and unsaturated fatty acids from 71.35 to 73.4% of total fatty acids of free lipids of three pearl millet varieties. Linoleic acid was the predominant unsaturated fatty acid which accounted for 46% of the total. Abdullahi and Rivista (1988) reported that corn germ lipids contained 46% linoleic, 36% oleic and 13.5% palmitic acid. According to Saker et al. (1986) wheat, maize and rice germ oils contained high concentration of unsaturated fatty acids i.e. 27.8, 27.0 and 17.8%, respectively of oleic acid, 41.9, 39.9 and 16.2% of linoleic, 2.4, 2.0 and 15.6% of linolenic and 73.0, 68.7 and 71.2%, respectively of total unsaturated fatty acids.

Starch digestibility of pearl millet has been known to be very low. According to Mahajan (1986) and Khetarpaul (1988) starch

digestibility of pearl millet (mg maltose released/g) was 12.0 and 18.7, respectively. Yoon et al. (1983) reported an increase in glycemic index as a result of improved starch digestibility which was attributed to the reduction of phytic acid.

Chauhan et al. (1986) reported that protein digestibility of pearl millet varied from 58 to 68 per cent. Khetarpaul (1988) found the protein digestibility of 59.2% in pearl millet sample.

Ramachandra et al. (1977) determined the effect of dehulling of finger millet on in vitro protein digestibility (IVPD) and found significant differences in dark brown whole and dehulled seeds. It was noticed that dehulling increased the IVPD. Pawar and Parlikar (1990) studied the effect of dehulling and soaking on in vitro protein digestibility of pearl millet. They observed the significant increase in IVPD from 66.3 to 82.8% after dehulling and soaking.

2.2 Antinutrients

The gray pigmentation of pearl millet is due to the presence of polyphenols. Polyphenols are predominantly located in the peripheral area of the seed. Vegetable tannins are defined as water soluble phenolic compounds having molecular weights between 500 and 3,000 and besides giving the usual phenolic reactions, these have special properties such as the ability to precipitate alkaloids, gelatin and other proteins. According to Loomis (1969) as much as 33% protein may be bound to phenolics through hydrogen bonding by which mechanism plant enzymes may be inactivated or precipitated. An appreciable amount of polyphenols of 788 and

761 mg/100 g has been reported by Mahajan (1986) and Khetarpaul (1988) in pearl millet flour which may partly account for its relatively low nutritive value.

The possible effects of seed coat polyphenolics on the nutritional quality of protein has been reported by Elias et al. (1979). Results obtained suggested that the pigments present in the seed coat contained high levels of tannins and other related polyphenols. Polyphenols can react with protein decreasing their digestibility and therefore, their quality (Haslam, 1974; Bressani and Elias, 1980), and also have been shown to inhibit the activity of digestive enzymes especially trypsin and amylase (Tamir and Alumet, 1969; Griffiths, 1979; Singh, 1984). Polyphenols and their oxidation products have known to react with protein; and may have three modes of reaction as suggested by Hulse et al. (1980). These are a) hydrogen bonds between OH groups in the tannins and receptor groups (e.g. NH, SH and CH) in the proteins, b) ion bonds between anionic groups in the tannins and cationic groups in the protein and c) covalent linkage between quinones and various reactive groups in the protein.

Watson et al. (1975) speculated that the insolubility of α-glucosidase and amylase might be due to formation of insoluble complexes between the tannins and the enzymes.

Reichert (1979) reported that the pH sensitive pigements in pearl millet are important from an aesthetic and nutritional point of view. Pearl millet seeds of many varieties are dark gray or yellow in colour. This pigmentation is markedly reduced

by the traditional practice of soakingdehulled seeds in sour milk or in aqueous extract of tamarind (tartaric acid). Dehulling is an important pre-requisite to rapid absorption of acid. Without any dehulling, whitening of the pearl millet grain requires upto 25 h because acid is only absorbed through the areas of the seed around the embryo. Dehulled seeds whiten rapidly (5-10 min at 90% extraction) because acid is absorbed through all areas where the hull has been cracked. According to Panwal and Pawar (1989) HCl was most effective bleaching agent which removed pigments in the pearl millet to the extent of 74.3% during 24 h soaking time. Pawar and Parlikar (1990) reported that polyphenolic pigments were reduced to 66.9 to 71.3 per cent in grains dehulled and soaked in 0.2N HCl from 20 to 45 min against 67.6% in grains dehulled and soaked in water for 15 h.

Chibbar et al. (1978) fopund that during dehulling of sorghum (BR 64) by Hill thrasher abrasion mill about 24% by weight of each grain was removed; 74% of the tannin was removed, accompanied by a loss of 1-2% protein content. The tannin content of RS 626 (low tannin sorghum) fell by 50%.

Price et al. (1979) reported that sorghum tannins appears to be reactive and easily modified to forms which don't respond to chemical tests for tannin. Treatments used by them were steam and dry heat, ammoniation and aqueous solutions of NaOH and K_2CO_3., Treatments in the absence of water were relatively less effective than comparable treatments with added moisture. Most of the treatments decreased the level of tannin, as measured by chemical tests, to 10-50% of the original level.

When seeds of pearl millet were dehulled by soaking for 1 min in conc H_2SO_4 followed by washing in water, and rubbing off the pericarp by hand, 80% of the total phenols and nearly 90% of the tannins were removed with corresponding increase in in vitro protein digestibility. Addition of tannic acid to dehulled pearl millet flour also lowered the IVPD but not to the same extent as in whole seed samples. Ramachandra et al. (1977) suggested that this difference could be due to the loss on dehulling of other polyphenolic compounds present in the seed coat.

Davis and Hoseney (1979) suggested that the selective absorption of polyphenolic substances occurs by sorghum starch. Deshpande and Salunkhe (1982) ascribed the lowered in vitro starch digestibility of legumes to their tannin absorption. Thompson et al. (1984) found a negative correlation between glycemic index and concentration of total polyphenols. The addition of tannic acid and phytic acid reduced the starch digestibility by 13 and 60 per cent after 5 h, respectively. Combined tannic and phytic acid reduced the digestibility at a level (63%) which did not differ significantly from that with only phytic acid.

Phytic acid, myo-inositol 1, 2, 3, 4, 5, 6-hexakis (dihydrogen phosphate) is one of the widespread occurrences in grains (O'Dell et al., 1972).

Importance of phytic acid in nutrition lies in its property of forming insoluble or nearly insoluble compounds with mineral elements including calcium, iron, magnesium and zinc, the resultant

phytates being excreted in faeces (Gontzea and Sutzescu , 1968). It is a form of storage cations as well as phosphorus in many seeds (Asada et al., 1969). Phytic acid occurs primarily in the outer seed coats and germ of plant seeds (Oberleas, 1973). More than half of the phosphorus in cearals is reported to be present in the form of phytic acid (Gopalan et al., 1981) which is not available in the human system. Courtois and Perles (1954) found 177 to 268 phytin P (mg/100 g) in pearl millet varieties. Chauhan et al. (1986) reported a wide variation in phytate content (594 to 1040 mg/100 g) among pearl millet varieties.

The quantity of phytic acid in cereals products depends to a large extent on the milling process and the extent to which bran and germ are separated from the endosperm.

Wang et al. (1959) examined the distribution of phytin P and of phytic acid in seven samples of sorghum. The tempered sorghum kernels were fractionated by a process of debranning, grinding, screening, air and gravity separation. The fractions obtained were germ (embryo), bran (seed coat layers), grits (endosperm) and mill fines endosperm mixed with germ and bran segments which were analysed for soluble p, phytin P, and total P. Phytic acid equivalent was calculated from phytin P using a factor of 3.55. Phytic acid was found maximum in germ ranging from 1920 to 680 mg/100 g followed by 670 to 1920 mg/100 g in bran. Grit contained only 70-640 mg/100 g as compared to 710 to 1170 mg/100 g in whole grain.

Endosperm of wheat and rice kernels is almost devoid of phytic acid, because it is concentrated in the germ and aleurone layers (pericarp) of the kernel cells. Corn differs from most other studied cereals in that 88% of the phytic acid is concentrated in the germ portion of the kernel (O'Dell et al., 1972). Because most of the phytic acid in cereals is located in the aleurone layers (bran), milling of cereals and subsequent separation of bran results in significant reduction of phytic acid in flours. Of the total 0.94 and 0.97% phytic acid of the whole wheat and rye, 0.85 and 0.61% was present in bran and 0.20 and 0.33% in flour of wheat and rye, respectively, when they were milled by Brabender Quard-rumat Junior mill (Reddy, 1976). Corn endosperm had small amounts (3.2%) of phytic acid but the major portion of phytic acid was in aleurone layers. In rice, 84.0 to 88.0% of the total phytic acid was reported to be in bran (Resurreccion et al., 1979).

Phytic acid and phytates may be decomposed by the enzyme phytase to produce inositol and phosphoric acid. Phytase is unequally distributed through the grain in somewhat the same manner as phytic acid. Giri (1938) stated the phytase activity of sorghum 0.76, pearl millet 0.17, whole wheat 0.12 and rice 0.03. Courtois and Perles (1954) also reported phytase activity of sorghum and pearl millet>1. Pawar and Parlikar (1990) studied the combined effect of dehulling and 0.2N HCl soaking on phytate content of pearl millet grains. Their results showed the phytate P decreased from 1.35 to 0.35 mg/g after dehulling and soaking. The removal of phytate was observed to be more in samples dehulled and soaked than the samples only dehulled. Further, the study showed that during soaking, phytate being soluble in aqueous solut-

ions at lower pH values got destroyed by phytase.

Satterlee and Abdul Kadar (1983) found that reducing the phytate content resulted in significant improvement of protein nutritional quality of wheat bran as demonstrated by both the rat-bioassay and in vitro protein digestibility.

Phytate binds with various essential metals, and reduces their availability absorption from the diet (Cheryan, 1980; Maga, 1982; Reddy et al., 1982; Wise, 1983) and reabsorption after their secretion in digestive juices (Davies and Nightingale, 1975).

Oberleas (1973) pointed out that phytate formation depends on pH as well as on the presence of secondary ions such as calcium Certainly calcium, iron, zinc, manganese and copper can be converted to insoluble phytates and thus rendered nutritionally unavailable.

2.3 Milling

Gast and Adrian (1965) and Adrian et al. (1967) used three milling methods for pearl millet.

i) Traditional pestle and mortar pounding

ii) mechanical commercial milling by SOTRAMIL (Societi de transformation du mill, Zinder, Niger)

iii) mechanical milling by SEPIAL (Societe d'dtuder et d' exploitation de procedes pour l industrie alimentaire)

Pestle and mortar grinding (Adrian et al., 1967) produced an edible fraction representing 85% of whole grain.

SOTRMIL uses decorticating (abrasive) rolls followed by a hammer mill to give a flour of 65-70% extraction rate.

SEPIAL process makes use of peeling-decortication. The conditioned grains are 'peeled' in an apparatus with a vertical axis with paddles, the action of which is sufficient to detach the moistened pericarp leaving the layers intact. The pericarp is then separated from the grains by brushes or aspiration. The 'decortication' is carried out by a vigorous rubbing in a brushing machine. Because of the preceding 'peeling' this brushing is sufficient to remove the remaining outer coat. This procedure gives a "protein-rich fraction" and decorticated grain. The products of the SEPIAL process, as % of whole grain were

	(%)
Whole grain	100
Pealed grain	92.5
Decorticated grain	84.0
Protein rich fraction	8.5

Under the microscope the protein-rich fraction was seen to consist of the aleurone and adjacent layers with a fair proportion of the germ and scutellum (Adrian et al., 1975). Dewit and Schwargart (1970) described how a rice mill was used to remove the bran by abrasion from cleaned pearl millet followed by reduction in a hammer or pin-disc mill.

Kurien et al. (1959) separated the husk and the endosperm of finger millet by a wet processing technique. Washed grain

was soaked for 24 h, then crushed in a stone grinder. The ground material was suspended in the soak water and filtered through a 100-mesh sieve. The residue husk remaining on the sieve was almost free from starch endosperm.

Kurien and Desikachar (1962) found that moistening finger millet with 3-7% water for about 2h, followed by grinding in a Wiley mill, produced fractions high in husk.A technique of wet processing was evolved by which the grain with original moisture content of 11% was steamed with 5% extra water for various periods. After cooling to room temp, the grain was milled (Wiley mill) using first 2 mm screen. The ground product was passed through 60-mesh sieve and designated fraction I. The residue was again Wiley milled using 1 mm screen and designated fraction II A steaming period of 2 min was found to give maximum flour yield, 35% fraction I and 34% fraction II. The residue was highly coloured and contained most of the husk.

Kurien and Desikachar (1966) treated a market sample of finger millet with various levels of added moisture before milling. The compared samples included: i) untreated, ii) 3% water for 10 min, iii) 5% water for 30 min, iv) 10% water for 45 min, v) 5% water, then steamed for 2 min, vi) steamed for 2 min and vii) dried to 3% moisture, then added 5% water for 15 min. The fractions for three break rolls, the three reduction rolls, and the residues (shuts and husks) were collected separately from

the Buhler Laboratory mill. The treatment (iii) gave maximum yield of flour (break and reduction rolls) with maximum colour. Treatment (ii), moisture below 5% gave a coloured flour with high fibre content. Treatment (iv), 10% moisture and steaming and treatments (v) and (vi), steaming, reduced flour yield; treatment (vii) gave a high yield (74%) of flour, containing a small amount of pulverized husk.

Reichert and Youngs (1976) reported that on the basis of relative efficiencies in terms of colour removal, kernel cracking and through put, the Hill grain thresher (abrasion mill) was to be preferred to the attrition mill. The abrasion mill also had advantages in relative size, maintenance requirements and relative simplicity for a village scale milling operation.

Reichert and Youngs (1977) studied the following processes of transformation.

i) traditional dehulling using a wooden pestle in a metal beaker, 20% by weight of water added before pounding in the mortar, air-drying and winnowing to remove the bran and other fines. The process was repeated twice to remove the approximately a) 10 b) 25 and c) 45% kernel.

ii) mechanical dehulling in a Strong Scott barley pearler

iii) mechanical dehulling with a Palyi Compact milling system (attrition type)

iv) mechanical dehulling with a Hill grain thresher (abrasive type)

The comparative dehulling efficiencies of the last three were discussed by Reichert and Youngs (1977) who stated that ii) and iv) were superior to iii). The Palyi Compact mill as described by deMan et al. (1973) was modified to include an adjustable cover plate to control the exit of grains from the cylinderical head. In the barley pearler, the metal screen surrounding the single carborandum stone was covered with a thin piece of rubber to prevent the passing of small seeds.

To remove the outer layers (pericarp) of the sorghum and millet, a separate decortication process, the Eurafric M 164 decorticator (Anon, 1969) was used. This consists of a metal carborandum coated cone with a conical rotor; the degree of decortication is regulated by adjusting the distance between the rotor and the cone. On leaving the cone, the bran and decorticated grain are thrown into a cylinderical sieve with brushes; the coarse bran is separated from the decorticated by aspiration.

Perten (1977) reported that soft wheat, pearl millet and sorghum gave different results when tempered to 16% moisture content and then milled in a Buhler Laboratory roller MLU 202 with three breaks and three reduction rolls. The sorghum brans were more easily pulverized than thewheat bran and appeared more prominently in the fine flour than in the course.

Chibber et al. (1978) suggested that Hill thresher caused both chipping and shearing of the kernel and removed not only

the outer bran layers but also some of the endosperm and embryo when sorghum was passed several times through a Hill thresher abrasion mill.

Traditional milling of millet is by pounding. Pounding is use of a mortar and pestle to remove the outer bran. Both dry and slightly wet (tempered) grains are used. After pounding, the outer can be removed by winnowing (Vogel and Graham, 1979).

Another traditional milling is the use of hand-operated stone mills and saddle stones with sufficient skill, the operator can produce meal of controlled particle size. The bran is removed by winnowing. In traditional milling, the separation generally involves removing only the outer part of the bran. The pericarp tends to separate in the mesocarp layer, so a considerable part of bran remains attached to the endosperm and germ (Hoseney et al., 1981).

The objective of dry milling is to separate the grain into its anatomical parts. The bran includes the pericarp, testa and aleurone. If the germ was obtained as a separate and intact entity, the endosperm would be then free from contamination and could be reduced to the desired particle size. Hubbard et al. (1950) manually dissected sorghum and reported the yield ranges from 80-85%.

In general the grain is tempered to make the bran tough and rubbery so that it will not grind easily. Tempering is also useful because it makes the endosperm soft and fragile.

Degermination is an important factor in sorghum dry milling. The germ is high in oils and must be removed if the flour grits are to be stored. Hahn (1969) recommended tempering and impact milling. The germ can be separated from the grits of the kernel if not broken into small pieces.

Abdelrahman et al. (1983) developed a simple milling system using roller mills for providing low-fat grits from pearl millet. Average yield of grits was 61% with a fat content of 1.20%. The system involved decorticating the grain, tempering to 22% moisture, and single-pass milling on finely corrugated rolls. The germ was more easily separated from the grain when the tempering moisture increased. Short tempering time gave better separation of germ and endosperm and, thus, better yield of low fat grits. Tempering was beneficial in producing grits or flour of small particle size.

Bookwalter et al. (1987) used two different pairs of Allis Chalmers corrugated rolls to reduce whole millet with or without temper water to desired particle sizes. A laboratory sifter and an aspirator were used to separate milled particles into medium and fine grits, flours, germ, hulls and shorts prior to either remilling or separating into final products.

Mistry and Eckhoff (1992) developed an alkali debranning process for yellow dent corn to obtain corn bran without disintegrating or splitting the kernel. Sodium hydroxide was found to be most effective alkali for loosening the pericarp of the kernel and subsequently separating it in a hydroabrasor leaving the kernel absolutely free from pericarp.

Desikachar (1986) found that short prior moist conditioning of sorghum grain with 2-3% moisture enabled removal of the bran by an abrasive machine similar to that used in rice milling.

A stepwise process for treatment of wheat as an adjunct to conventional milling was described by Posner et al. (1986). The process premits recovery of substantial quantity of wheat embryo and scutellum, thereby increasing yield of premium germ while enhancing storability of the resultant flour by virtue of removal of high oil germ fractions. The process involves : initial tempering of wheat followed by impact scouring to remove intact embryo; deembryonated wheat is subjected to a second tempering step prior to milling.

Defrancisco et al. (1982) studied the behaviour of pearl millet and sorghum with Shepherds' modification of Udy cyclone mill. Sorghum bran was removed in large flakes during decortication, and pearl millet was removed in smaller flakes. Neither sorghum nor pearl millet was degermed during decortication.

Perten (1983) found differences in milling characteristics of wheat, sorghum and millet when they were ground in a hammer mill under the same conditions without tempering. The whole flour (100% extraction rate) was separated into fine and coarse fractions by sieving on a sieve with 125 um openings. Sorghum and millet flours contained more ash and fat in fine than in coarse fraction because the fine fraction contained more bran and germ-contrary

to what occurred in wheat, which had higher ash and fat content in the coarse particles. The bran coat and part of the germ of sorghum and millet are easily pulverized to a fine powder, which is difficult to separate from the flour by sieving. UMS (United Milling Systems A/s) sorghum/millet dehuller has been introduced by Gamble Carlsberg viz,. 8, Denmark. Its important part is the retrieval of endosperm chuncks in the bran flour by the centrifugal and air sifters.

2.4 Storability

Pearl millet, a small seeded tear-shaped grain weighs approximately one third that of grain sorghum. The germ comprises a major portion of the kernel and contains the largest proportion of lipid material. The total lipid content averages 7% and lipids are composed of approximately 70% unsaturated fatty acids. Hydrolytic and oxidative changes in lipids are responsible for the poor storage quality of milled pearl millet.

Pearl millet can be stored for long periods without dramatic quality changes if the kernels remain intact but once the grain is subjected to grinding, the meal quality rapidly deteriorates. The solution of the storage instability of milled pearl millet lies, therefore, in developing milling processes that remove the major lipid containing portions of the grain (i.e. germ and the covering layers).

Inspite of greater availability, low cost and comparatively good nutritional value, use of pearl millet in food industry is very

low as compared to other cereals. Pearl millet flour develops unpleasant odour and often a bitter taste when stored for more than 7-10 days.

Carnovale and Quaglia (1973) suggested that the rapid deterioration of quality of pearl millet flour during storage for 3 months stems mainly from hydrolytic rather than oxidative decomposition of lipids. They also noted changes in fatty acid composition in their millet flours during storage. Palmatic acid level decreased by 2.2 to 4.5 per cent while levels of stearic, oleic and linolenic acids declined to a lesser degree during the storage. But linolenic acid levels in free-lipid fraction increased during storage.

Lai and Varriano-Marston (1980) found the changes in sensory attributes (odour), mould count, fatty acid composition, total titrable acidity and peroxide value when pearl millet meal was stored at 19°C, 58 per cent relative humidity, and at 42°C, 75 per cent relative humidity.

Chaudhary (1981) found that the maximum increase in free fatty acid content (ranging from 8.60 to 12.87 per cent) during storage was in flour stored in gunny bag and minimum in samples stored in polythene bag. The amounts of free fatty acids in flour of HC 6 were higher than in the flours of other two pearl millet varieties under all storage conditions. There was 39 to 92 per cent increase in the fat acidity during storage. The data further showed that HC 6 which contained the highest free fatty acid content had become more rancid as revealed by maximum increase of peroxide

value. Storage conditions enhanced the lipase activity in all flour samples.

According to Kaced et al. (1984) increase in fat acidity and peroxide values indicated that millet rapidly became rancid after it was ground. Fat acidity and peroxide value of stored whole pearl millet grain did not vary significantly over the same time period showing that deterioration occurred more rapidly in ground millet than in whole grain. When millet meal was stored in polythene bags, the peroxide value increased rapidly and appeared to signal the start of rancidity. However, pearl millet meal stored in cotton bags showed no peroxide accumulation. Free fatty acids and fat-acidity data indicated that all the acidity produced during storage was the result of free fatty acids. The proportions in which free fatty acids were released were similar to those found in total fatty acids. Therefore, the hydrolytic action of lipase appeared to be random. Total fatty acids did not significantly change as a result of storage. Thus, no significant oxidative degradation of fatty acids occurred during storage. Reconstitution studies of millet meal and wheat meal and their lipid showed that the fat content was the major factor contributing to rapid increase of fat acidity in ground millet.

Patel and Parameshwarn (1992) found that the moisture content of pearl millet flour increased continuously during storage. The flour did not develop off flavours possibly because the moisture was less than 12%, the critical moisture content required for develop-

ment of off flavour. Their results showed that the lipase activity as well as free fatty acid levels not only increased during storage but also showed high fluctuations as observed in lipase activity during storage of oats and wheat. With progress in storage time, a continuous increase in peroxide value/levels was seen.

Lai and Varriano-Marston (1980) in their histochemical studies on pearl millet indicated that lipase activity was located mainly in the germ, pericarp, and aleurone and subaleurone layers. Decortication procedures would probably reduce lipid changes during storage, but the germ remaining in decorticated kernels would assure continued oxidative and lipolytic activity.

Nichaev et al. (1972a,b,c) studied lipase and lipoxygenase activities in stored oats and attributed storage losses of 18:2 to lipoxygenase oxidation. Lipase activity in oats increased during storage (Kazakov et al., 1972), with TG being the main substrate (Salun and Kalugina, 1974).

Gardner and Inglett (1971) studied the inactivation of lipase, and lipoxygenase in roll-cooked germ, these being the enzymes most likely to affect storage stability. Significant enzyme inactivation occurred when the harvested grain was dried. Cooking the germ on rolls heated at 124°C completely inactivated the enzymes. Lipoxgenase was the most heat-sensitive of enzymes studied.

Dhaliwal et al. (1991) reported lipolytic and lipoxygenase changes in milled rice obtained from short, medium and long grain

varieties of paddy. Drying of paddy before storage lowered the free fatty acid content of milled rice, apparently due to decreased lipolytic activity at low moisture levels. Free fatty acid content increased significantly during storage, due to lipolytic activity over a prolonged period. Drying of paddy before storage did not affect lipoxygenase activity, but activity increased significantly during storage. Lipids and lipolytic enzymes concentrated in the outer layers of the brown rice kernel (Barber, 1972; Kennedy et al., 1974; Pomeranz et al., 1975) are the cause of lipolytic and oxidative rancidity problem in stored rice (Barbar, 1972; Bhat et al., 1975; Juliono, 1979). Deterioration is greater at higher temperature and moisture levels (Matsuda and Hirayama, 1973; Sidhom et al., 1975b). For millet flour to have good storage quality, the grain must be decorticated to approximately 20% and the flour must have moisture content less than 10%. Under these conditions, millet flour can be kept for several months (Perten et al., 1983).

Steeping prior to parboiling accelerates lipolysis before the lipases are more or less completely inactivated by the heat of parboiling (Carnacini et al., 1972). Lipolysis in milled rice bran is very rapid. Lipid inactivation can be achieved by heat treatments (Viraktamath and Desikachar, 1971).

2.5 Food products

Food products can be produced from whole, cracked, or ground pearl millet. One of the commonest methods is to decorticate

(dehull) the kernel before grinding it to various particle sizes for use in different products. Pushpamma and Rao (1981) found that two-thirds of the consumers in the Indian state of Andhra Pradesh decorticated grain. In most areas of Africa, a significant portion of the pearl millet is decorticated.

Rotis are unleavened, flat breads made from pearl millet in India (Subramanian and Jambunathan, 1980; Pushpamma and Rao, 1981).. Several standardized laboratory procedures have been proposed for use in evaluating sorghum and millet cultivars for roti quality (Murty and Subramanian, 1982; Olewink et al., 1984). The grain is often milled to produce a fine flour. The ground grain in sifted to removed course pieces and warm water is added to knead the dough .The dough is thin hand pressed in to a thin wide circle and baked. Report published by ICRISAT (1986) on sorghum and millet elaborated the standardize procedure for preparation of thick porridge. The results showed that varying quantities of flour were cooked for different periods from 1 to 15 min with an interval of 1 min. Varying quantities of water (40, 45, 48 and 50 ml) was also used. Based on the data, cooking 10g flour with 50 ml water for 7 min was selected. Porridge quality was subjectively evaluated for consistency using a score of 1-5, where 1 was poor and 5 was excellent. Porridge quality of the cultivars DSA 74, SAD 448 and Fakiaybad were rated high.

Kheterpaul (1988) prepared three different types of Chappaties after the addition of raw pearl millet flour (Chappati A), whole wheat flour (Chappati B) and whole wheat flour and besan (Chappati C) to the fermented pearl millet flour. All the three types of chappaties were in the slightly liked category.

MATERIALS AND METHODS

3.1 Materials

In order to have preliminary information on the range of lipid content of pearl millet grain, seeds of sixty high yielding strains were obtained from the Senior Bajra Breeder, Department of Plant Breeding, Haryana Agricultural University, Hisar. For various treatments and milling of the grains, seeds of HC-4 a commonly grown pearl millet cultivar of this area were procured from the Manager, Haryana Seed Development Corporation, Hisar. The seeds were pooled together, freed of extraneous matter and proceeded further for various treatments.

3.2 Treatments

Before the grains were milled through different milling machines, these were given different treatments including tempering, blanching, steeping in water, acid or alkali steeping followed by blanching.

3.2.1 Tempering

After taking into account the moisture content of the grains, a measured quantity of distilled water was added to the grains, so as to give the final moisture level of 12, 14 and 16% in the grains. For obtaining this, air-tight plastic containers were used. After addition of water by spraying gently, this contents in the plastic containers were thoroughly agitated and mixed. At each moisture level, moistened grains were kept in air-tightly closed plastic containers for 2, 4 and 6 h at room temperature.

3.2.2 Blanching

Distilled water was brought to boiling in an aluminium container. The seeds in the muslin cloth were loosely tied and then transferred to boiling water

and kept for 3, 6 and 9 min. After the blanching treatment, grains were spread on a sheet of paper and dried at room temperature to a constant moisture level (10-12%). The dried grains were kept in air tight containers for further use.

3.2.3 Steeping

Grains were soaked in distilled water contained in an aluminium container for 3, 6 and 9 h. A grain to water ratio of 1:4 (w/v) was taken. The soaked seeds were taken out of the water and spread over a sheet of paper and dried to a constant level of moisture (10-12%).

3.2.4 Acid steeping and blanching

Grains were soaked in 0.2N HCl contained in a glass container for 6 h. A grain to 0.2N HCl ratio of 1:4 (w/v) was taken. After draining off the HCl solution, grains were put in muslin cloth and shifted to boiling water and kept there for 3,6 and 9 min. The blanched grains were rinsed with water and spread over a sheet of paper and dried to a constant moisture level (10-12%).

3.2.5 Alkali steeping and blanching

Grains were soaked in 0.5% $Ca(OH)_2$ solution contained in a glass container for 6 h. A grain to solution ratio of 1:4 (w/v) was taken. After draining off the alkali solution, the grains were put in muslin cloth and shifted to boiling water and kept there for 3, 6 and 9 min. The blanched grains were rinsed with water and spread over a sheet of paper and dried to a constant level of moisture (10-12%).

3.3 Milling equipments

Strong Scott Barley Pearler (Seedburo Equipment Co., Chicago, USA), McGill No. 2 and 3 Rice Polisher (Seedburo Equipment Co., Chicago, USA) in the

Department of Food Science and Technology, Punjab Agricultural University, Ludhiana and Tangential Abrasive Dehulling Device (Venables Machine Works Ltd. Canada) in the Department of Crop Science and Biochemistry, ICRISAT were employed for milling the treated and further processed pearl millet grains as discussed in section 3.21 to 3.25.

3.3.1 Barley pearler

Grains in this machine are abradded on a carborandum wheel fitted vertifically. Dehulled grain and husk are collected in a receptacle and separated by sieving into dehulled grain and husk.

Weighed 100 g sample and transferred to the receiving cup of the barley pearler. The barley pearler mill was switched on for 2-8 min. scouring time. Removed the dehulled grains from the mill and sieved it through 20/32 mesh size sieve to separate the husk and dehusking grains. Weighed the dehulled grains and calculated the per cent dehulled grain and husk.

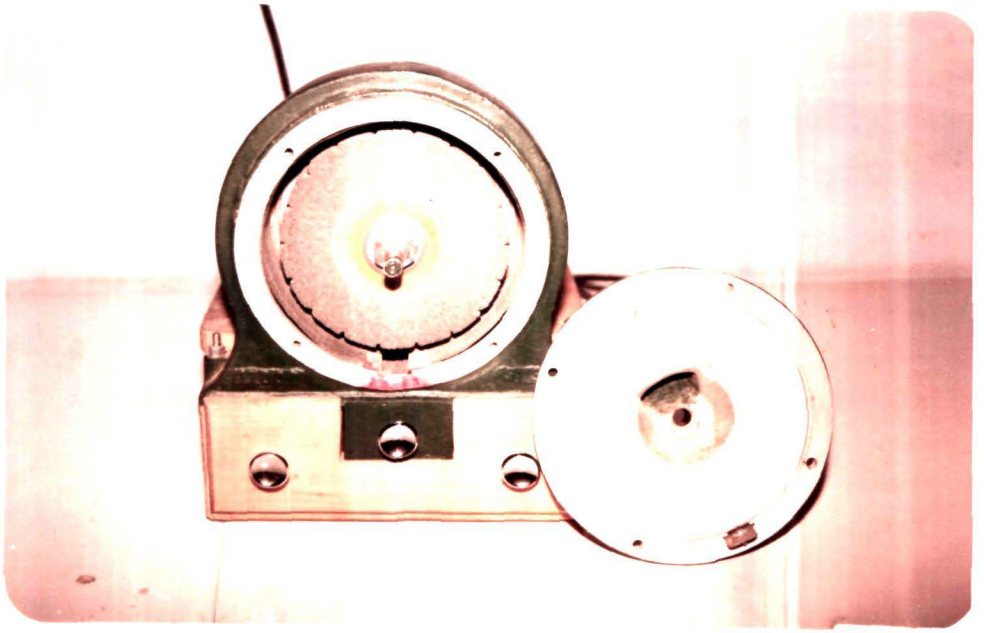
$$\text{Dehulled grain recovery (\%)} = \frac{\text{Wt of dehulled grains}}{\text{Wt of whole grain taken}} \times 100$$

3.3.2 McGill No. 2 rice polisher

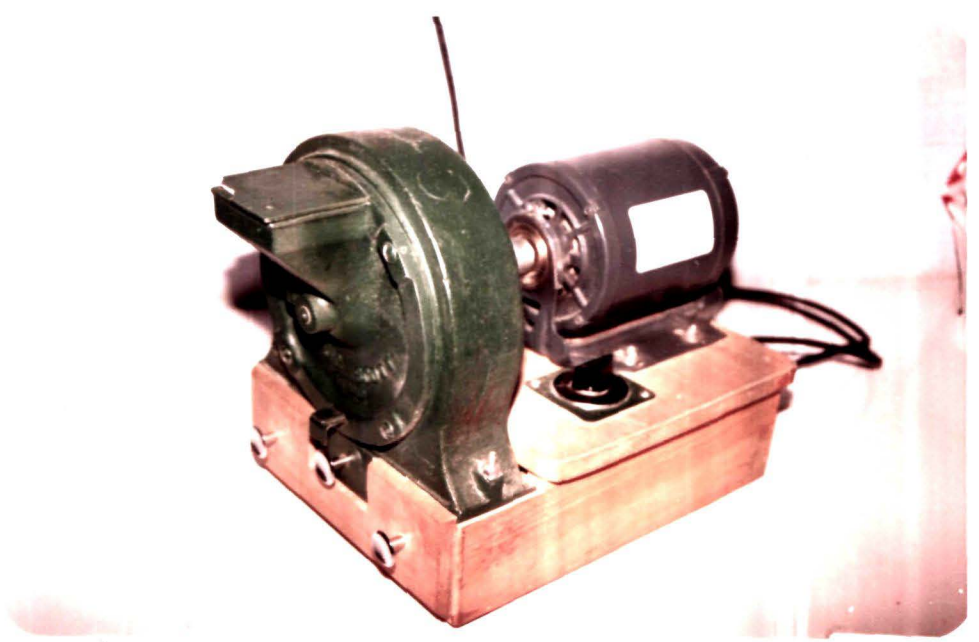
The No. 2 instrument is equipped with a weight level assembly and strainless steel pressure cover. Sample weighing 100 g was inserted, pressure cover was closed and pressure was applied for 1-4 min. The dehulled grains and husk were collected and separated by passing through a 20/32 mesh sieve.

3.3.3 McGill No. 3 rice polisher

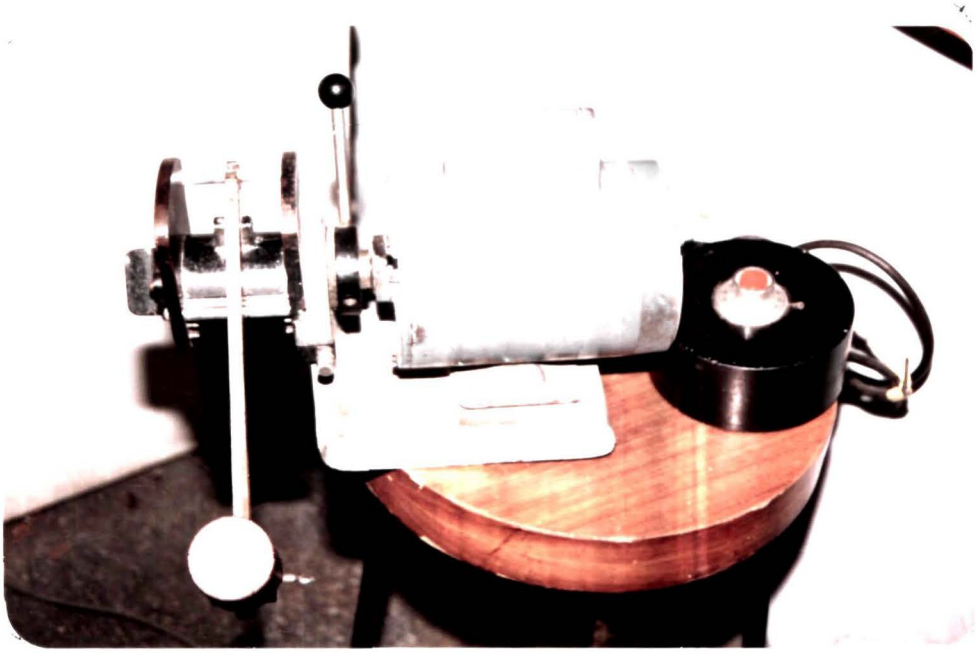
A sample size as big as one kg can be milled with this instrument at a time. Milling pressure is controlled with iron weights in increments of 1/2 lb



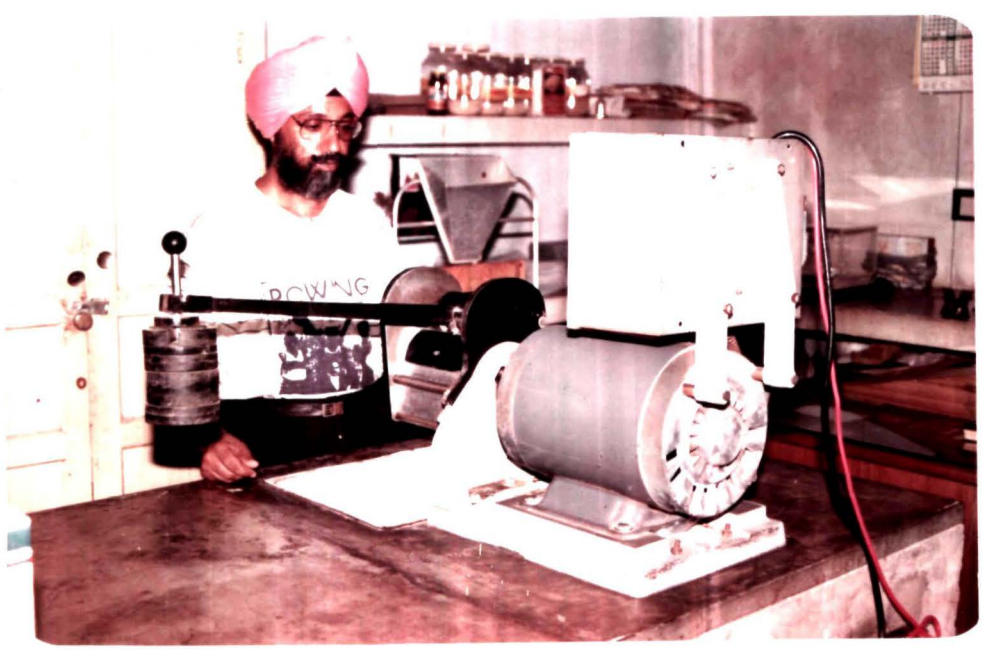
Strong Scott Barley pearler
(I ternal view)



Strong Scott Barley pearler
(External view)



McGill No. 2 Rice Polisher



McGill No. 3 Rice Polisher

upto 10 lbs for a wide range of milling results. The interior surfaces of the instrument which are in contact with grain are hard chromeplated and rust free. Grains were put in and milled for 1 to 4 minute.

3.3.4 Tangential abrasive dehulling device

The dehuller TADD, model 4E-230 (Manufacturers: Venables Machines Works Ltd. East Saskatoon, Saskatchewan, Canada) is based on the principal of tangential abrasion. Abrasion is provided by a rotating horizontally mounted grinding wheel. Sample cup plate was positioned. The sample was put in bottomless sample cups which rests on the surface of the grinding wheel. The timer automatically controlled the duration of run, during which the grains rolled freely in the sample cups were dehulled and they came in contact with the grinding wheel. The grinding wheel also produced a uniform mixing action that moved the seeds from the bottom to the top of the sample cup. Dehulled grains were removed from the sample cups with a vaccum aspirating device, weighed and the weight loss (%) was designated as the yield of bran.

3.4 Screening for fat content

Seeds of 60 varieties of pearl millet and two fractions of milled grains obtained from milling (3.31 - 3.34) were screened for their fat content by Nuclear Magnetic Resonance (NMR) (Medsen, 1976).

3.5 Selection of treatments

Depending upon the recovery of endosperm fraction and fat content of germ and endosperm grit fraction, the following treatments were selected for carrying out milling by the equipments available and for further chemical,

nutritional and storage studies on endosperm fraction.

Barley pearler

i- Tempering at 16% moisture level for 4 h.

ii- Six min blanching.

iii- Nine min. blanching

iv- Six h steeping in 0.2N HCl followed by blanching for 9 min.

v- Six h steeping in 0.5% calcium hydroxide solution followed by blanching for 9 min.

McGill No. 3 Miller

i- Tempering at 14% moisture level for 4 h.

ii- Tempering at 16% moisture level for 2 h.

iii- Tempering at 16% moisture level for 4 h.

iv- Tempering at 16% moisture level for 6 h.

v- Nine min blanching.

vi- Six h steeping in 0.2N HCl followed by blanching for 9 min.

For one group pearl millet grains as such without any treatment were milled by both the mills.

The fractions obtained after milling the untreated and treated grains were stored in air tight plastic bottles in a deep freezer (-20°C).

3.6 Nutritional evaluation

3.6.1 Crude fat

Crude fat was estimated by employing the standard method of analysis (AOAC, 1980) using the Soxhlet extraction apparatus.

Procedure :

Weighed about 5 g of dry sample and transferred it to an extraction thimble dried overnight at 105°C. Placed the thimble in a Soxhlet extractor

fitted with a condenser and flask containing sufficient petroleum ether. The extraction was carried out for 6 h. After the extraction, thimble was removed with the sample from the extraction apparatus and dried in the hot air oven to a constant weight. Cooled in a desiccator to room temperature and weighed. The loss in the weight of the thimble was the estimate of the ether extract in the sample.

3.6.2 Ash

Ash in the sample was estimated by employing the standard method of analysis (AOAC, 1980).

Procedure :

Took 5 g oven dried sample in the weighed crucible. Ignited it till no charred particles remained in the crucible. Then put the crucible in muffle furnance (500°C) for 5-6 h or till a white ash was obtained. Cooled the crucible in a desiccator and weighed. The loss in weight represented the organic matter and residue, the ash content.

3.6.3. Crude protein

Reagents:

i- N/100 H_2SO_4

ii- Boric acid (4%)

iii- Mixed indicator solution: Took 0.5 g bromocresol green and 0.1 g methyl red and dissolved in 100 ml 95% ethanol and adjusted the solution with drops of dilute NaOH or HCl to bluish purple colour.

iv- NaOH (45%)

v- Digestion mixture: 10 g K_2SO_4, 0.5 g $CuSO_4.6H_20$ and 2 g $FeSO_4$.

Procedure :

Took 1 g sample and digested with 25 ml conc H_2SO_4 and a pinch of digestion mixture. The nitrogen in ammonical salt was distilled with 45 percent NaOH in a Kjeldahl apparatus. The ammonia liberated was absorbed in 10 ml boric acid solution containing a few drops of mixed indicator and titrated against standard H_2SO_4 (N/100). The end point was indicated by the change of colour. A factor 6.25 was applied to convert the amount of nitrogen to crude protein.

3.6.3.1 Non protein nitrogen (NPN)

Non protein nitrogen was estimated by the method of Bhatty and Finlayson (1973) as modified by Singh and Jambunathan (1981).

Reagents :

10% TCA : Dissolved 10 g Trichloroacetic acid (TCA) in water and made to 100 ml.

Procedure :

Weighed 1 g defatted sample and transferred it to a centrifuge tube and added 15 ml of 10% TCA; shook it for 1 h. Centrifuged the contents at 1000 rpm for 15 min. Washed the residue twice with 5 ml of 10% TCA solultion and saved the supernatant and made up final volume to 25 ml. Nitrogen content of supernatant was determined by Microkjeldahl method (AOAC, 1980).

3.6.3.2 True protein nitrogen

Non protein nitrogen was subtracted from the total protein nitrogen to work out the true protein nitrogen. A factor of 6.25 was used to convert TPN to true protein.

3.6.4 In vitro protein digestibility

In vitro protein digestibility of protein was carried out by the method of Axtell et al. (1981) as modified by Mertz et al. (1983).

Reagents :

i- Pepsin reagent : 0.1 M KH_2PO_4 (pH 2.0) containing 0.2% pepsin; dissolved 13.6 g potassium phosphate in1 lt water, adjusted pH of the solution to 2.0 and dissolved 2 g pepsin (Sigma) in the buffer.

ii- TCA (50%): Dissolved 50 g trichloroacetic acid in water and made up volume to 100 ml.

Procedure :

Weighed 250 ml sample and transferred it to a centrifuge tube.To it 20 ml of pepsin reagent was added. Stoppered the tubes and arranged them in a shaker-incubator maintaining the water temperature at 37°C for 3 h. Removed the centrifuge tubes and cooled them. Added 5 ml 50% TCA and centrifuged the contents at 10,000 rpm for 10 min at room temperature andfiltered if necessary. Digested 10 ml clear aliquot for nitrogen determination by microkjeldahl method (AOAC, 1980). Digested protein of sample was determined. Protein digestibility was calculated by following formula.

$$\text{Protein digestibility (\%)} = \frac{\text{Digested protein}}{\text{Total protein}} \times 100$$

3.6.5 Available carbohydrates

Total soluble sugars other than starch were extracted according to the procedure of Cerning and Guilhot (1973).

Twenty five ml ethanol (80%) was added to 500 mg sample in a round bottomed flask connected to a condensor and kept on a heating mantle for 30 min

with occasional strirring. The extract was cooled, centrifuged at 8000 rpm for 30 min and supernatant was collected. The above procedure was repeated twice, each time extracting the residue in 25 ml of 80% ethanol. The combined extract in beaker was evaporated to dryness on a boiling water bath. The residue was dissolved in distilled water and made to 50 ml.

3.6.5.1 Total soluble sugars

Total soluble sugars were estimated by the method of Yemm and Willis (1954).

Reagents :

i- Standard sugar solution: Twenty five mg glucose was dissolved in water and made to 100 ml. This solution contained 250 ug glucose per ml. For obtaining a standard curve, 0.1 to 1.0 ml of this solution was used.

ii- Anthrone reagent (0.2% anthrone in 70% H_2SO_4) : This reagent was prepared freshly daily and allowed to stand for 30 to 40 min before use.

Estimation :

Ten ml freshly prepared anthrone reagent was pipetted in a test tube (150 x 25 mm) and chilled in ice cold water. One ml sugar extract was taken and diluted to 10 ml with water. One ml of the diluted sugar extract was taken and layered on the acidic anthrone reagent. After cooling for 3 to 5 min, the contents were thoroughly mixed while still immersed in ice cold water. The contents in the tube were heated vigorously in a boiling water bath for 10 min and then immediately cooled in cold water. The absorbance was then read at 625 nm in Spectronic-21 against a suitable blank.

The amount of sugars was then determined by referring to a standard curve previously prepared with glucose.

3.6.5.2 Reducing sugars

Reducing sugars were estimated by Somogy's modified method (Somogy, 1945).

Reagents :

i- Copper reagent A : Twenty five g anhydrous sodium carbonate, 25 g potassium sodium tartarate, 20 g sodium bicarbonate and 200 g anhydrous sodium sulphate were dissolved in about 800 ml distilled water and diluted to one litre.

ii- Copper reagent B : Fifteen g $CuSO_4$ was dissolved in 100 ml distilled water containing two drops of HCl.

iii- Arsenomolybdate reagent : Twenty five g ammonium molybdate was dissolved in 450 ml distilled water by warming. Twenty one ml conc H_2SO_4 was added with stirring. Three g sodium hydrogen arsenate was dissolved in 25 ml distilled water with stirring. The solution was kept in an incubator at 37°C for 24 h before use. This reagent was stored in a glass stoppered brown bottle.

iv- Cooper reagents A and B were mixed in the ratio of 25:1 (v/v) before use.

v- Standard sugar solution : Twenty five mg glucose was dissolved and made to 100 ml with water. This contained 250 ug glucose per ml.

Estimation :

One ml test extract was taken in a blood sugar tube graduated at 25 ml. One ml mixed copper reagent (iv) was added and then heated for 20 min. in a boiling water bath. To this, one ml of arsenomolybdate reagent was added, mixed thoroughly and the contents were diluted to 25 ml. A stable blue colour

appeared quickly which was read at 520 nm in Spectronic-21 against suitable blank. The amount of reducing sugar was then determined by referring to the glucose standard curve.

3.6.5.3 Non-reducing sugars

The amount of non-reducing sugars was calculated as the difference between total soluble sugars and reducing sugars.

3.6.5.4 Starch

Starch from the sugar free pellet was estimated by the method of Clegg (1956).

Extraction :

Five ml water was added to aforesaid residue of test material and while stirring 6.5 ml of 52% perchloric acid was added. The contents were stirred continuously for five min and then occasionally for next 15 min. To this 20 ml water was added and centrifuged at 8000 rpm for 20 min. The supernatant was settled in a 100 ml volumetric flask. Five ml water was added to the residue and repeated the extraction with 52% perchloric acid, stirrring occasionally for next 30 min. The contents of the tube were washed into a volumetric flask containing the test extract and made it to 100 ml with water. It was then filtered discarding first 5 ml of filtrate . A suitable aliquot of the extract was used for glucose estimation using anthrone reagent by the method of Yemm and Willis (1954). Starch was calculated by using the following formula:

Starch = Glucose x 0.9

3.6.5.5 Starch digestibility (*in vitro*)

In vitro starch digestibility was assessed as per the method of Singh *et al.* (1982).

Reagents :

i- 0.2M phosphate buffer (pH 6.9) : Fifty ml 0.2M potassium dihydrogen phosphate was added to 46.8 ml 0.2M disodium hydrogen phosphate and made up to 200 ml.

ii- Pancreatic amylase : Twenty mg pancreatic amylase (Sigma Chemical Company, USA) was dissolved in 50 ml 0.2M phosphate buffer (pH 6.9).

iii- Dinitrosalicylic reagent: Ten g of 3,5-dinitrosalicylic acid, 300 g sodium potassium tartarate and 16 g NaOH were dissolved in carbondioxide free water and made to 1000 ml. The reagent was stored in brown bottle and protected from carbon dioxide.

iv- Standard maltose solution : One hundred mg maltose monohydrate was added in water and made up to 100 ml.

Estimation :

A suitable amount of defatted sample (25 mg) was dispersed in one ml 0.2 M phosphate buffer (pH 6.9). Pancreatic amylase (0.5 ml) was added to sample suspension and incubated in water bath at 37°C for 2h. After the incubation period was over, 2 ml dinitrosalicylic acid reagent was quickely added and the mixture was heated for 5 min in a boiling water bath. After cooling, the solution was made to 25 ml with distilled water and filtered prior to measurement of absorbance at 350 nm. A blank was run simultaneously by incubating the sample; the dinitrosalicylic acid reagent was added before addition of the enzyme solution. Maltose was used as standard and values were expressed as mg maltose released / g defatted sample. Standard was prepared by taking 0.8 to 8 mg maltose from a standard maltose solution.

3.6.6 Total minerals :

One g ground sample was taken in a 150 ml conical flask. To this 25-30 ml diacid mixture (HNO_3: $HClO_4$ :: 5:1 v/v) was added and kept overnight. Next day it was digested by heating till clear white precipitates settled down at the bottom. The crystals were dissolved by diluting in double distilled water. The contents were filtered through Whatman No. 42 filter paper. The filtrate was made to 50 ml with double distilled water and was used for determination of total Ca, P, Zn and Fe.

3.6.6.1 Phosphorus

Phosphorus was determined colorimetrically by the method of Chen et al. (1956).

Reagents :

i- Ascorbic acid (10%).

ii- Ammonium molybdate (2.5%).

iii- Reagent C : Mixed 6N H_2SO_4, water 2.5% ammonium molybdate and 10% ascorbic acid in the ratio of 1:2:1:1 (v/v), respectively. This reagent was prepared fresh every day.

ov- Standard phosphorus solution : Dissolved 0.351 g pure and dry anhydrous monopotassium dihydrogen orthophosphate in a few ml water and 10 ml 10N H_2SO_4. The volume was made to one litre with water. This stock solution contained 80 ug P/ml stock solution to one litre which served as working standard solution. It contained 2 ug P/ml.

Two to three drops of chloroform were added for preserving the solution.

Procedure :

Pipetted a suitable aliquot (1 ml) of the mineral extract in a test tube and made the volume to 4 ml with water. Added 4 ml reagent C and

mixed well. Incubated the contents at 37°C in a water bath for 90 min. Removed and allowed to cool to room temperature and read absorbance at 820 nm against a suitable blank. Standard curve was plotted using one to eight ug P.

3.6.6.2 Calcium

Calcium in the digested sample was determined by the Atomic Absorption, Spectrophotometer.

3.6.6.3 Trace minerals

Trace minerals including iron and zinc in acid digested samples were determined by the Atomic Absorption Spectrophotometer AA 120, in the Department of Soils, Haryana Agricultural University, Hisar according to the method of Lindsey and Norwell (1969).

3.6.6.4 HCl extractable minerals

Minerals including calcium, phosphorus, iron and zinc were extracted in 0.03N HCl (Peterson et al., 1943) and estimated in the extract to assess availability of these minerals in the samples.

To one g sample, 50 ml 0.03N HCl was added. The mixture was incubated at 37°C in a shaker-cum-waterbath for three h to simulate conditions that occur in human stomach. The mixture was then filtered through an ashless filter paper (Whatman No. 42). The filtrate was oven dried, digested in the diacid mixture and proceeded for the determination of individual minerals as in 3.6.6.1 to 3.6.6.3.

3.6.7 Fatty acid composition

The lipids were extracted by the method of Huber and Newman (1975). The 5g flour was thoroughly mixed and then boiled for 3 min in choloroform

methanol (2:1, v/v) containing 2 drops of 0.1% BHT per 100 ml of chloroform : methanol mixture as an antioxident followed by grinding in a glass homogenisor. The homogenate was filtered and transferred to a separating funnel. The filtrate was washed by the method of Suzuki (1965). To the filtrate was added anhydrous sodium sulphate to remove any residual water. The lipid extract was used for further analysis.

Fatty acids of total lipids of pearl millet flour were converted into methyl esters by the method of Luddy et al. (1968).

Reagents :

i- Sodium methylate (0.4N): To 400 ml methanol (moisture free), added 4.7 g metallic sodium slowly and in small amounts. When mixtures returned to room temperature, made the volume to 500 ml with methanol.

ii- Carbon disulphide :

Procedure :

One ml lipid extract was taken in a screw capped vial. The chloroform was evaporated to dryness by keeping the vial in waterbath at 70°C. Then 0.25 ml 0.4N sodium methylate was added and the vial was capped. The vial was then immersed in waterbath at 65°C and shaken vigorously for 30 sec. The heating was continued without shaking for additional one and half min. The fatty acid methyl esters so prepared were separated, identified and quantitated on a gas chromatograph with a flame ionisation detector. The column was 2 meter x 3.2 mm in size and packed with 20% DEGS on 100/120 chromosorb W. Temperature at injection port, column and FID was 200, 180 and 210°C, respectively. The peaks were identified by comparing the relative

retention times with those of reference fatty acids run on the same column under the same conditions. Relative peak areas were determined by multiplying the peak height with width of the peak at half height.

3.7 Storability :

About 200 g bajra and fraction-I sample was ground to fine powder in a Cyclotec sample mill using 0.5 mm sieve. The flour so obtained was stored in air tight wide mouthed plastic bottles at 25, 30 and 35°C for 15 and 30 days. After the storage period the samples were analysed for the following :

i- Free fatty acids

ii- Lipase activity

iii- Fat acidity

iv- Peroxide value

v- Lipoxygenase activity

v- Sensory evaluation.

3.7.1 Peroxide value :

Peroxide value was determined by the method of AOAC (1980).

Reagents :

i- Acetic acid : chloroform solution (3:2 v/v).

ii- Saturated potassium iodide solution.

iii- 0.01N Sodium thiosulphate solution.

iv- Starch solution : One g soluble starch was dissolved in cold distilled water to make thin paste. Then boiling distilled water was added and boiled for one min while stirring. When completely dissolved the volume was made to 100 ml.

Five g lipids were taken in conical flask. Thirty ml acetic acid chloroform mixture was added to the flask and swirled to dissolve. Then 0.5 ml saturated potassium iodide solution was added, kept for one min with occasional shaking and 30 ml distilled water was added. This was slowly titrated against 0.01N sodium thiosulphate with vigorous shaking until yellow colour almost disappeared. Then 0.05 ml starch solution was added and titration continued shaking vigorously to release all iodine from chloroform layer until blue colour just disappeared. The blank was run in the similar way. Peroxide value as meq peroxide per 1000 g sample.

$$= \frac{(S-B) \times N \times 1000}{\text{Wt of sample}}$$

where,

B = Volume (ml) of $Na_2S_2O_3$ used for titration of blank,

S = Volume)ml) of $Na_2S_2O_3$ used for titration of sample

N = Normality of $Na_2S_2O_3$ solution

3.7.2 Free fatty acids

Free fatty acids in the fat were determined by method of American Oil Chemists Society (1981).

Reagents :

i- Sodium hydroxide (0.25N) - Dissolved 10 g sodium hydroxide in water and made upto 1 lt with water

ii- Isopropyl alcohol (99%) - Neutralized isopropyl alcohol with 0.1N NaOH solution to a pink colour before adding to sample.

iii- Phenolphthalein indicator solution : Dissolved 1 g phenolphthalein in 95% ethyl alcohol and made up volume to 100 ml.

Procedure :

Five g sample was taken into an Erlenmeyer flask. Fifty ml neutralized isopropyl alcohol was added to it and sample was dissolved completely. Phenolphthalein indicator was added and titrated against 0.25N NaOH to pink colour end point which persisted for 30 seconds.

$$\% \text{ FFA} = \frac{\text{ml} \times N \times F \times 100}{\text{Sample wt} \times 1000}$$

where,

ml = ml of NaOH required

N = Normality of NaOH solution

F = Equivalent wt (282) of FFA (Oleic acid).

3.7.3 Lipase activity :

Lipase activity was expressed as the percentage of oleic acid on a fat basis using the AACC (1976) quick method for free fatty acids :

$$\text{Lipase activity} = \frac{\% \text{ FFA}}{\% \text{ Fat}} \times 100$$

3.7.4 Fat acidity :

The fat acidity was determined by method of AOAC (1980).

Ten g sample was extracted with petroleum ether on Soxhlet apparatus. The solvent of the extract was completely evaporated on steam bath. The residue was dissolved in extraction flask with 50 ml benzene-alcohol-phenolphthalein solution and titrated with standard potassium hydroxide (1 g/litre) to orange pink colour. Blank titration was made on 50 ml benzene-alcohol phenolphthalein and this value was substracted from titration value of the sample.

Fath acidity was calculated as mg of potassium hydroxide required to neutralize free fatty acids from 100 g flour.

Faty acidity = 10 x (T-B)

where,

T = ml KOH required to titrate sample ext.

B = ml KOH required to titrate blank.

3.7.5 Lipoxygenase activity :

Lipoxygenase activity was determined using a modification of the method of Summer (1943). The enzyme extract was obtained by grinding 5 g sample with 25 ml distilled water in a mortar and pestle. The sample was filtered through Whatman No. 1 filter paper and the filtrate was used as enzyme extract. Two ml enzyme extract was taken in a test tube and to this 10 ml ammonium thiocyanate (5% in 3% HCl) and 2 ml ferrous ammonium sulphate (5% in 3% HCl) were added. Absorbance was measured at 520 nm on a Spectronic-20 Spectrophtometer. Results were expressed as :

$$\text{Enzyme activity (ul of } O_2\text{/g/min)} = \frac{\text{Total } Fe^{+++}}{\text{Time of reaction (min)} \times \text{Weight of sample in enxyme extract}} \times 0.2866$$

3.7.6 Sensory evaluation :

Sensory evaluation of stored samples were carried out by a panel of judges for colour and aroma using six point hedonic scale (Appendix -2).

3.8 Utilization of milled fraction :

Following types of products were prepared from milled pearl millet.

3.8.1 Chapati

Ingredients :

Pearl millet flour (fraction -I)	= 100 g
Water	= To knead the dough
Salt	= 1/4 tsp.

Method :

Mixed the salt in pearl millet flour. Added water to knead the dough, rolled into chapati and baked it on the hot tawa.

3.8.2 Porridge

Ingredients :

Pearl millet (Fraction-I)	= 50 g
Milk	= 100 ml
Water	= 100 ml
Sugar	= 1 tbsp.

Method :

Added pearl millet , milk and water in the pressure cooker. Added sugar to it and cooked at 15 psi for 15 min. Served hot.

3.8.3 Khichdi :

Ingredients :

Pearl millet (Fraction -I)	= 50 g
Gramdal	= 15 g
Water	= 200 ml
Salt	= 1 tsp.
Red chill powder	= A pinch

Method :

Soaked the pearl millet fraction-I for 10-20 min in water. Mixed pearl millet grain and water in pressure cooker. Added salt and chilly powder to it. Cooked at 15 psi for 15 minute. For whole pearl millet cooked it for 30 min.

3.8.4 Pearl millet cake :

Ingredients :

Pearl millet flour (Fraction-I)	= 50 g
Sugar	= 50 g
Hydrogenated vegetable oil	= 25 g
Eggs	= 2 No.
Baking powder	1/4 tsp.

Method :

Ground sugar finely in an electric grinder. Creamed sugar and egg. Sieved pearl millet flour and added baking power to it. To this mixture oil was added. Poured the mixture in baking container and baked the cake in oven at 105°C for 15 min.

3.8.5 *Biscuits :*

Ingredients :

Pearl millet flour (Fraction -I)	- 100 g
Sugar	- 75 g
Water	- 30 ml
Hydrogenated vegetable oil	- 50 g
Ammonia powder (Ammonium chloride)	½ tsp
Baking powder	- ¼ tsp.

Method :

Ground sugar finely in an electric mixer. Creamed sugar and hydrogenated vegetable oil. Sieved flour and added baking powder to it. To the creamed sugar and oil mixture, added flour and made a dough with the help of water. Added ammonia powder to the dough. Rolled it and cut into the shape of biscuits with the help of a cutter. Baked biscuits in the oven at 150°C for 15 min.

3.8.6 Organoleptic evaluation :

The products developed milled pearl millet were evaluated for colour, flavour, taste, texture and appearance by a semitrained panel of judges deploying a 9 point hedonic scale as given in the Appendix-III. Average of the scores for all these characteristics was expressed as overall acceptability.

3.9 Statistical analysis :

The data were subjected to statistical analysis for analysis of variance and correlation coefficients in a completely randomised design according the standard methods (Panse and Sukhatme, 1961).

RESULTS AND DISCUSSION

The results of the study aimed at diversifying the uses and enhancing utilisation of pearl millet grains have been presented and discussed under the following heads and sub-heads.

4.1 Screening of strains for fat content

4.2 Milling and recovery of fractions

4.3 Nutritional value of milled fractions

4.3.1 Macronutrients

4.3.1.1 Fat and ash

4.3.1.2 Crude protein, true protein and non- protein nitrogen

4.3.1.3 Available carbohydrates

4.3.2 *In vitro* protein and starch digestibility

4.3.3 Polyphenols and phytic acid

4.3.4 Minerals

4.3.5 Fatty acid composition

4.4 Storability

4.5 Product development

4.1 Screening of the strains for the fat content

Sixty strains/varieties of pearl millet, including cultivar HC-4 the seeds of which were used for milling, nutritional evaluation of the fractions, storability and utilisation of the fractions in human humen diet, were screened for fat content by nuclear magnetic resource (NMR). Fat content of whole grains ranged from 4. 6 to 9.6 g/100 g (Appendix-I). As the seeds of the strain containing the highest

concentrations of fat were not available in sufficient amount for conducting the study, therefore the HC-4, most common cultivar in the state and containing medium level of fat, was used in the investigation. It was also observed that there was a difference in the values of fat content determined by NMR and Soxhlet method; NMR values were relatively higher. For example, HC-4 showed 6.03 and 6.72 per cent fat by Soxhlet and NMR methods, respectively.

4.2 Milling and recovery of fractions

The following mills were tested for separating germ, bran and endosperm of pearl millet grains.

i) Tangential Abrasive Dehulling Device (TADD)

ii) Scott Barley Pearler

iii) Rice Polishers
a) McGill Rice Polisher b) Rice Polisher Satake

4.2.1 Tangential Abrasive Dehulling Device (TADD)

Milling by TADD did not separate germ from the grain satisfactorily. This observation rested on inability of milling operations to dislodge germ and create groove in pearl millet grain. On further milling, grains were abrased to a greater extent resulting in more removal of upper layer of endosperm and contaminating the bran with endosperm grits. Hence the deployment of this mill for further study was abandoned.

4.2.2 Scott Barley Pearler

Pearl millet grains were milled using scouring time of 2, 4, 6 and 8 min. Fraction I representing endosperm and fraction II containing major portions of bran and germ were collected sepa-

rately. Fat content of both the fractions was expressed as g/100 g and in absolute amount as g. Anticipating improved recoveries of the fractions and fat in fraction II, the grains were given different treatments including tempering by raising moisture levels to 12, 14 and 16% and conditioning the moistened grains for 2, 4 and 6 h (Table 4.1). Besides tempering treatments, grains were also blanched in boiling water for 3, 6 and 9 min with and without steeping in 0.2N HCl for 6 h. Recovery and fat content of the fractions were determined (Table 4.2). Steeping grains in water for 3, 6 and 9 h and then milling resulted in excessive breakage of grains and hence milling of steeped grains and further study of the milled fractions was dropped.

In untreated grains fraction I and fraction II after milling for 2 min formed 90.0 and 9.8 per cent of grains and contained 5.8 ad 10.7 per cent fat, respectively. Proportion of fraction II increased as scouring time was raised from 2 to 8 min. In a similar way concentration of fat in fraction I decreased and that in fraction II increased simultaneously with increase in scouring time (Table 4.1). Grains after tempering, blanching and steeping-blanching showed almost the same trend in per cent recovery and fat content (%) of milled fractions (Tables 4.2 and 4.3; Figs 1-3, 7 &8). At every moisture level i.e. 12, 14 and 16 per cent an increase in tempering period resulted in lower recovery of fraction I at a fixed scouring time. There was a gradual decrease in fraction I recovery with an increase in scouring time at every moisture level and tempering period.

Table 4.1 : Effect of tempering on recovery and fat content of the fractions of pearl millet grain milled by barley pearler

Tempering moisture level (%)	Tempering period (h)	Scouring Time (min)	Recovery (%)		Fat content			
			Fraction-I	Fraction-II	Fraction-I		Fraction-II	
					(%)	Absolute	(%)	Absolute
1	2	3	4	5	6	7	8	9
12	2	2	95.5	4.53	6.21	5.93	9.22	0.42
		4	88.4	11.5	5.85	5.17	11.0	1.25
		6	85.1	14.8	4.85	5.13	14.0	2.08
		8	79.8	20.5	4.57	3.65	13.9	2.83
	4	2	95.5	4.20	6.15	5.86	9.26	0.39
		4	88.0	11.6	5.79	5.10	11.5	1.33
		6	84.0	15.2	4.80	4.04	14.3	2.17
		8	81.2	18.4	4.65	3.78	14.0	2.58
	6	2	93.0	6.40	6.02	5.60	9.80	0.62
		4	88.1	12.0	5.54	4.88	11.8	1.41
		6	82.1	17.6	4.42	3.63	14.2	2.48
		8	79.0	20.8	4.47	3.54	14.0	2.91
14	2	2	94.0	5.80	6.10	5.63	9.61	0.55
		4	90.1	9.60	5.83	5.25	12.0	1.15
		6	84.4	15.5	4.84	4.08	14.3	2.22
		8	80.2	19.5	4.50	3.60	15.1	2.75
	4	2	93.4	6.05	6.08	5.68	9.12	0.55
		4	87.9	11.5	5.70	5.01	11.4	1.43
		6	84.0	15.8	4.56	3.83	14.0	2.33
		8	80.0	19.4	4.51	3.59	14.1	2.73

Contd.....

Table 4.1 Contd.....

1	2	3	4	5	6	7	8	9
	6	2	90.9	8.68	6.00	5.46	10.3	0.90
		4	87.0	12.4	5.64	4.90	11.5	1.44
		6	83.0	16.7	4.49	3.73	15.0	2.51
		8	78.0	21.9	4.44	3.46	14.1	3.09
16	2	2	94.0	5.35	6.05	5.69	9.71	0.52
		4	90.4	9.57	5.80	5.24	11.6	1.12
		6	84.0	15.4	4.64	3.91	14.9	2.29
		8	80.0	19.8	4.42	3.54	14.0	2.78
	4	2	92.7	6.60	6.00	5.56	11.0	0.73
		4	89.0	9.82	5.67	5.06	14.0	1.36
		6	84.7	13.5	4.50	3.81	16.4	2.21
		8	79.8	19.4	4.78	3.81	15.8	3.06
	6	2	92.0	7.07	5.99	5.51	11.4	0.61
		4	87.8	11.9	5.21	4.58	13.0	1.56
		6	85.0	15.0	4.67	3.97	15.4	2.31
		8	78.1	18.2	4.68	3.64	14.1	2.58
Control		2	90.2	9.80	5.84	5.25	10.7	1.05
		4	86.5	13.1	5.26	4.55	13.4	1.76
		6	82.4	17.2	4.23	4.23	16.0	2.75
		8	77.4	22.1	3.87	3.00	15.8	3.50
Pooled CD (P 0.05)			1.96	1.21	0.10	0.06	0.20	0.31

Values are means of four determinations.

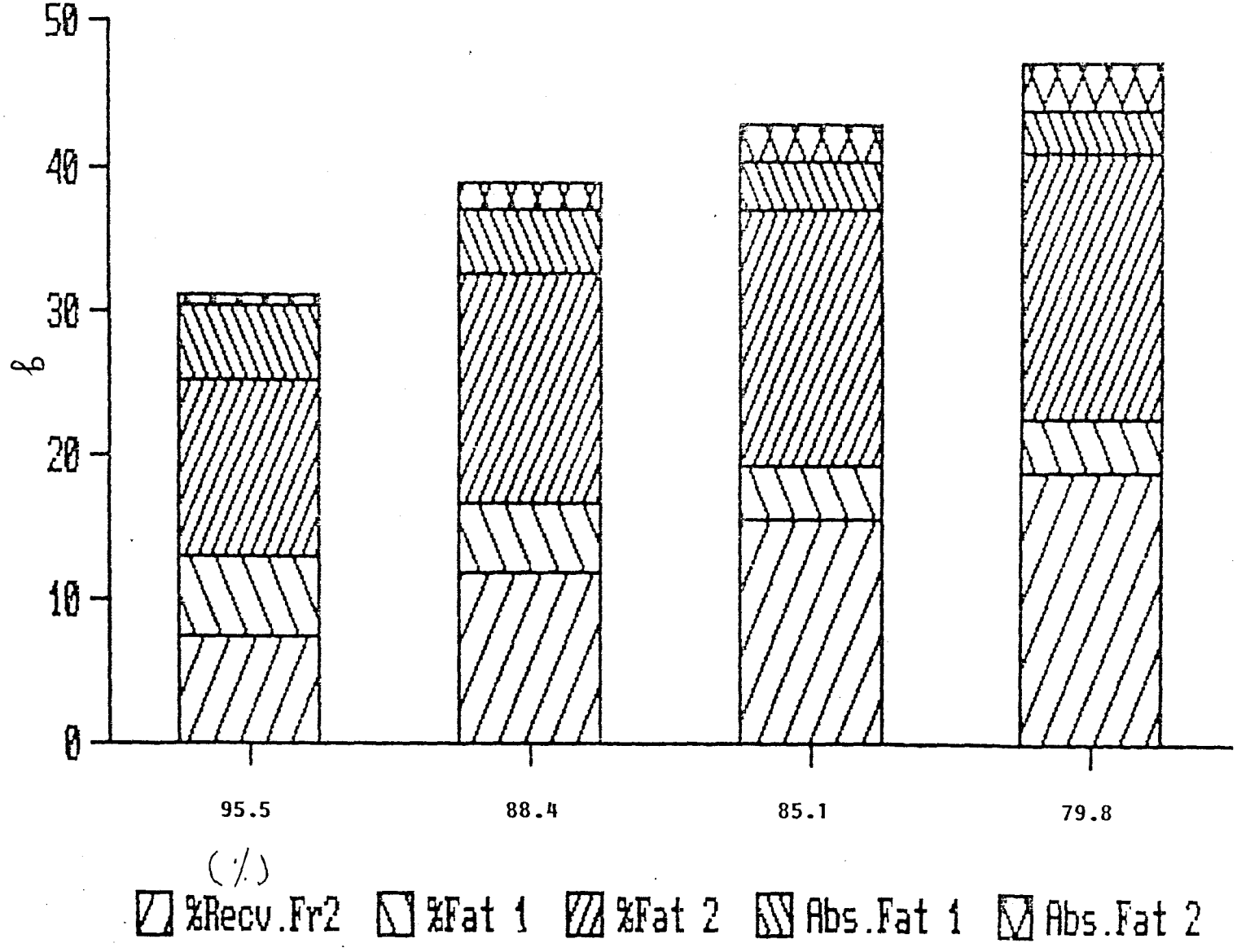


Fig 1a. Recovery and fat content of fractions of tempered grain (12%2h) milled by barley pearler

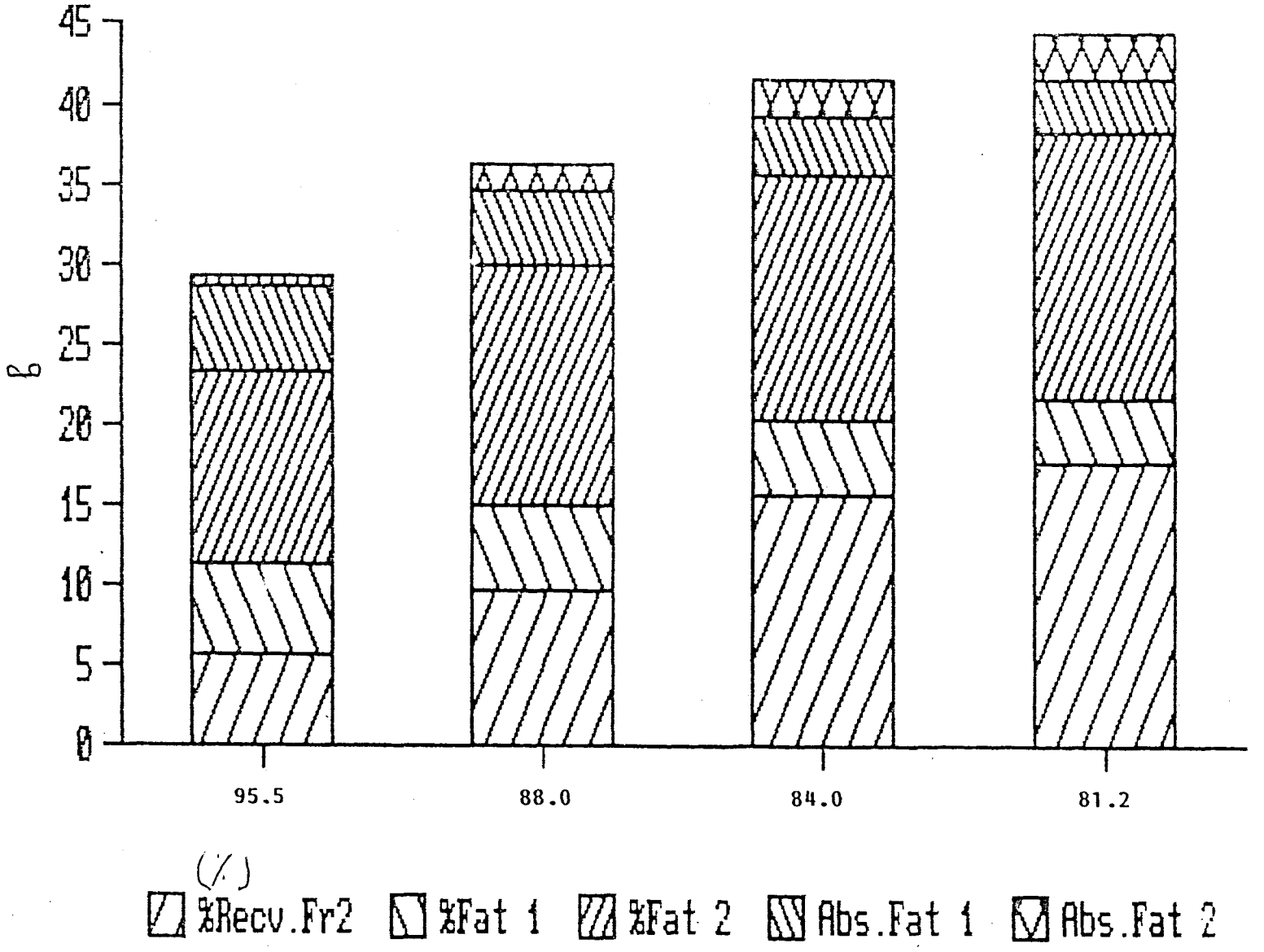


Fig 1b. Recovery and fat content of fractions of tempered grain (12%mh) milled by barley pearler

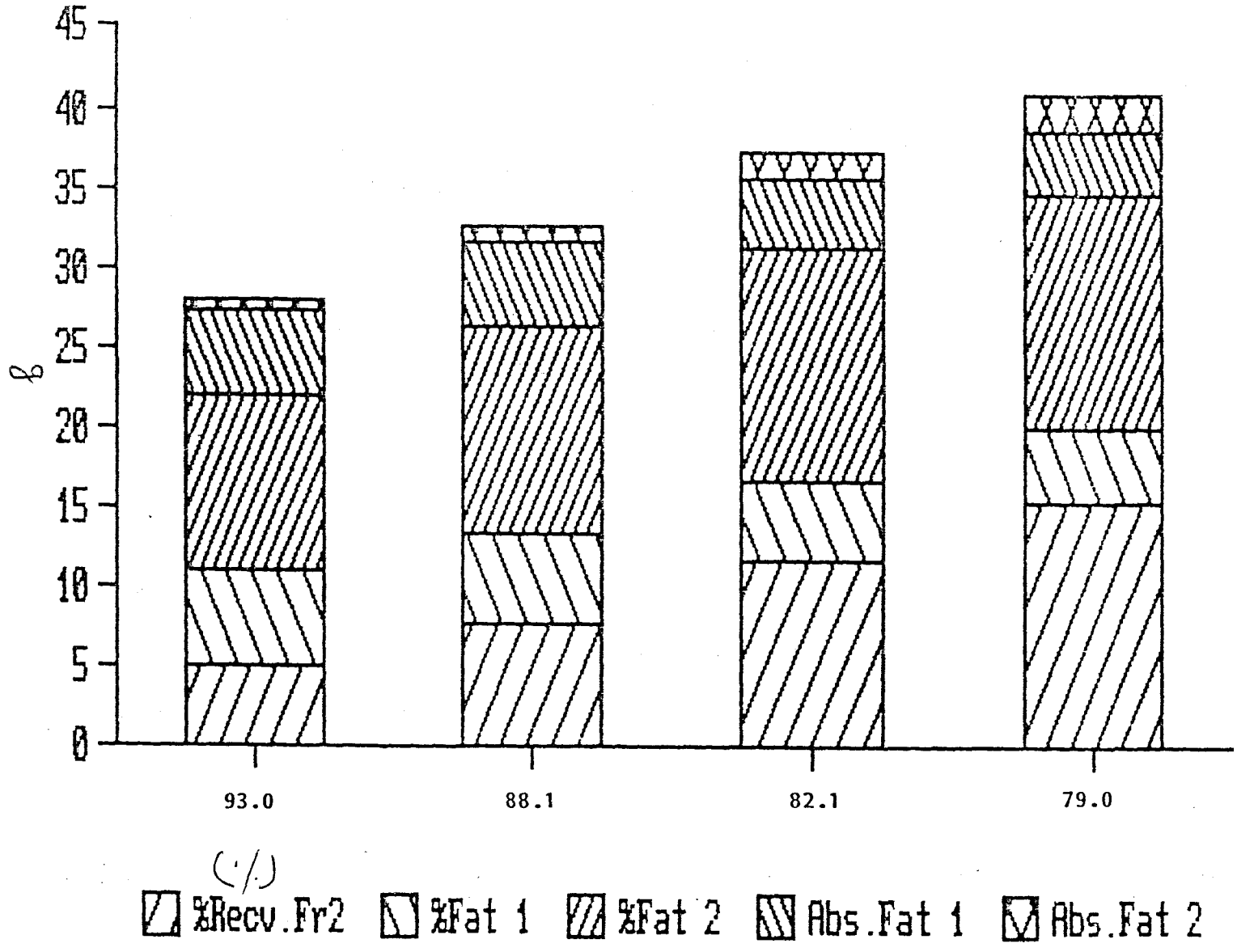


Fig 1c. Recovery and fat content of fractions of tempered grain (12%,6h) milled by barley pearler

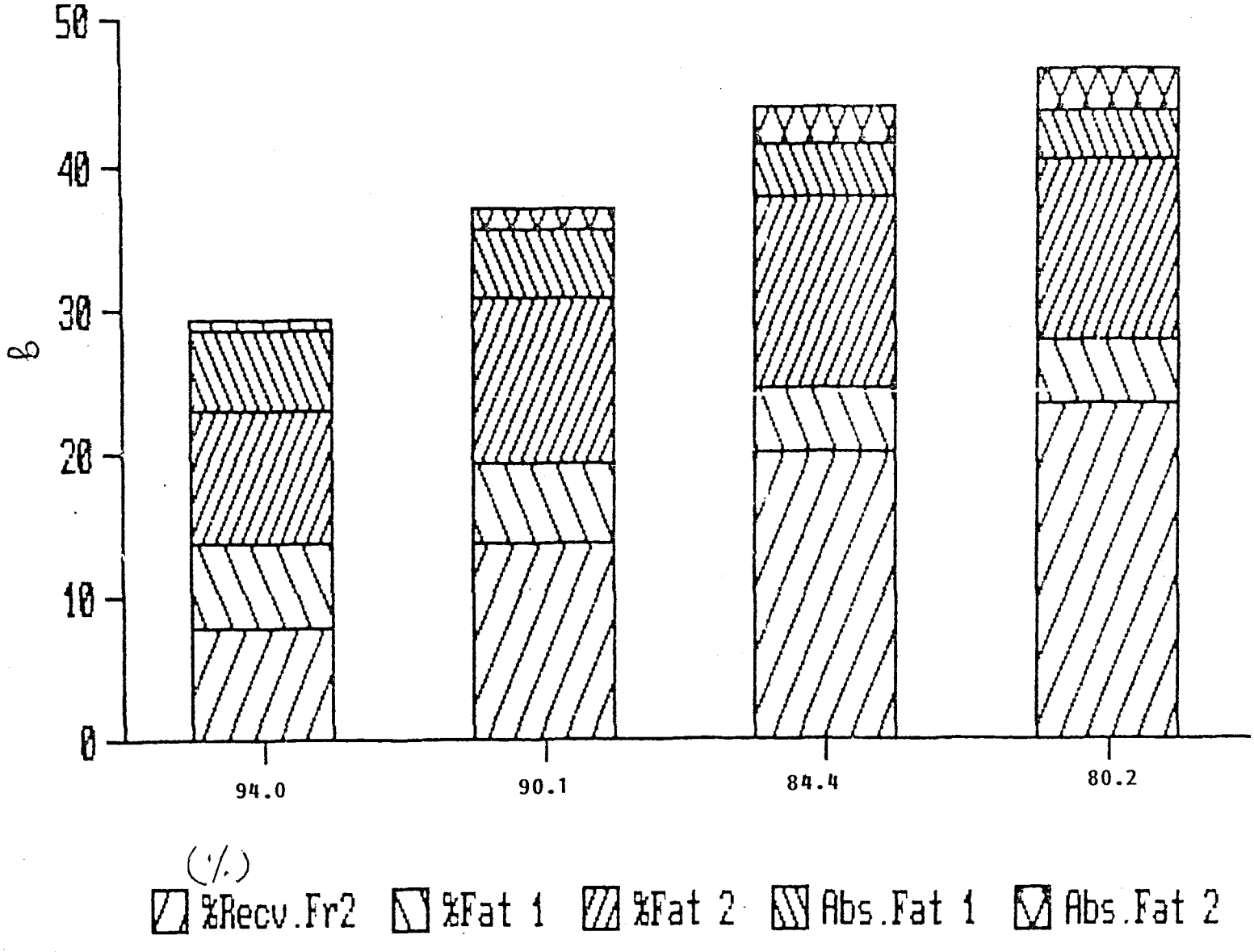


Fig 2a. Recovery and fat content of fractions of tempered grain (14%, 2h) milled by barley pearler

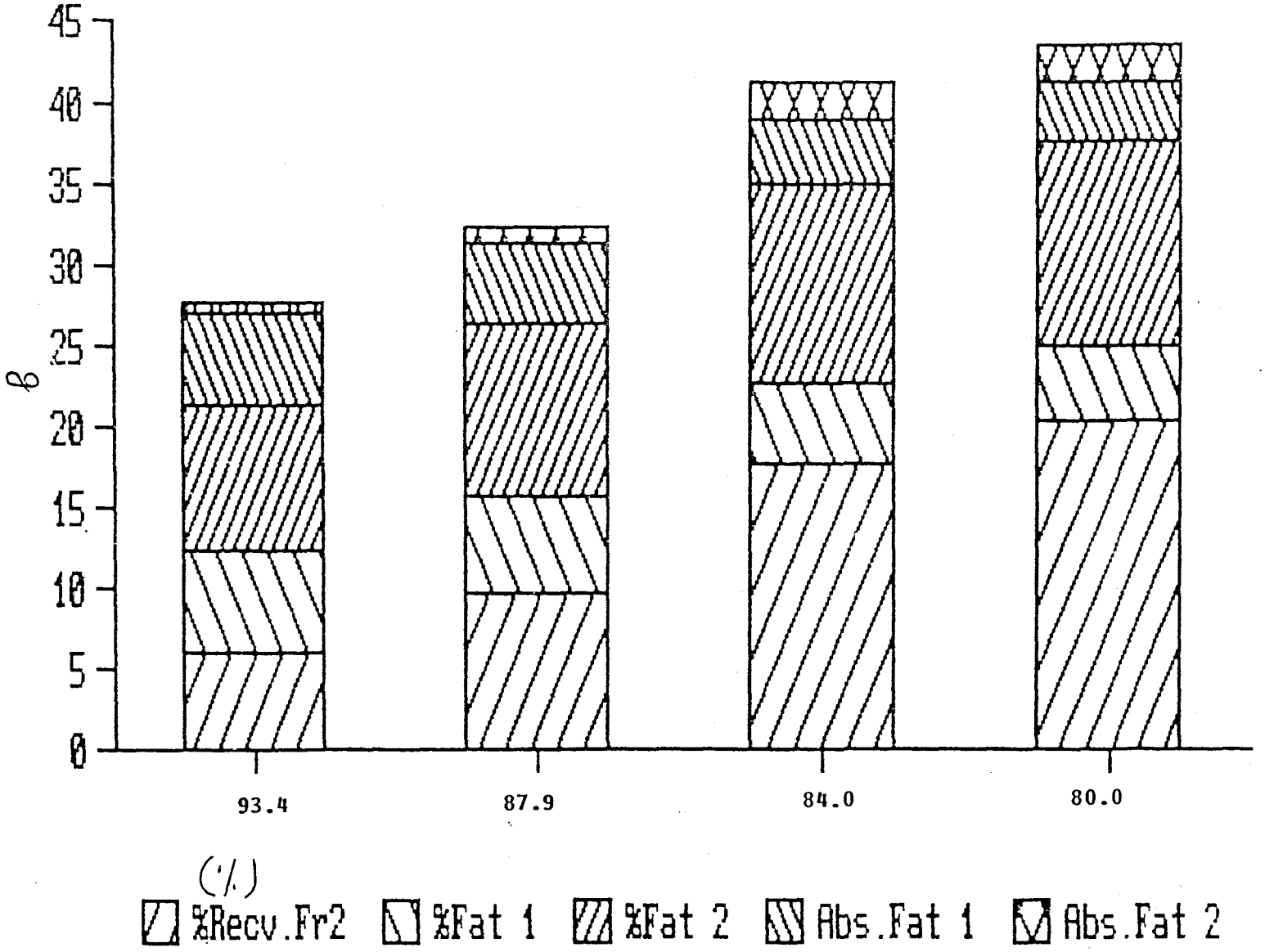


Fig 2b. Recovery and fat content of fractions of tempered grain (14%, 4h) milled by barley pearler

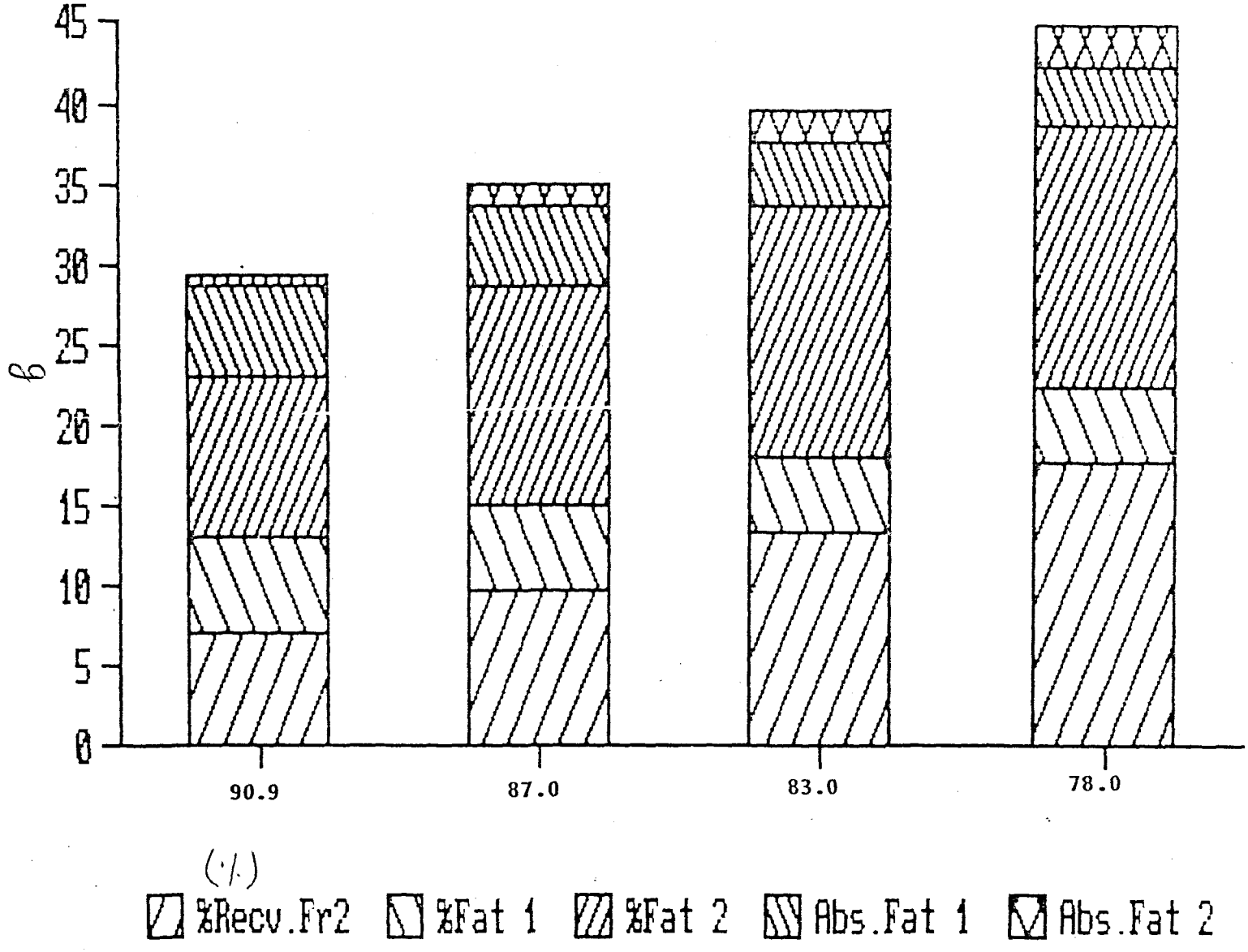


Fig 2c. Recovery and fat content of fractions of tempered grain (14%, 6h) milled by barley pearler

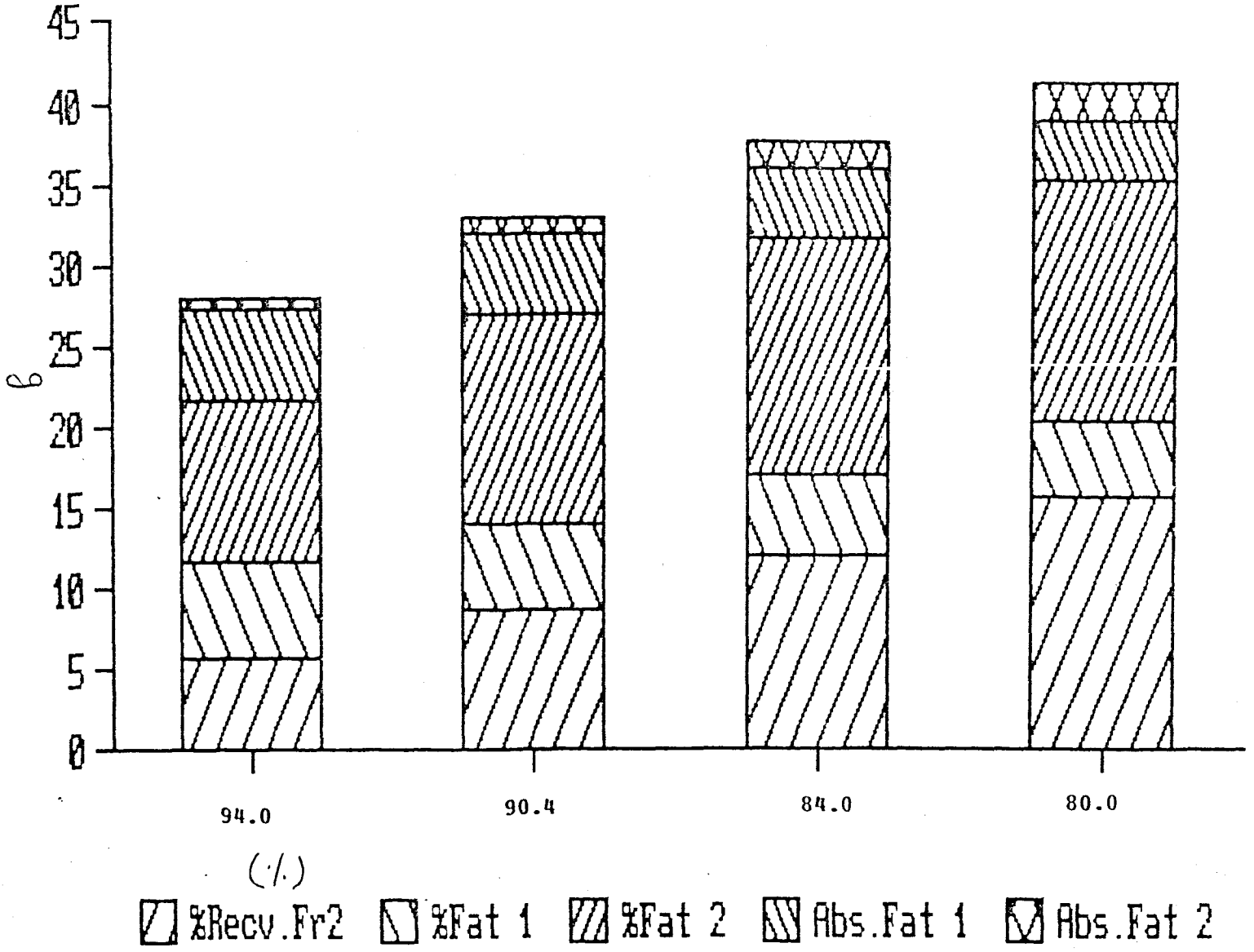


Fig 3a. Recovery and fat content of fractions of tempered grain (16%, 2h) milled by barley pearler

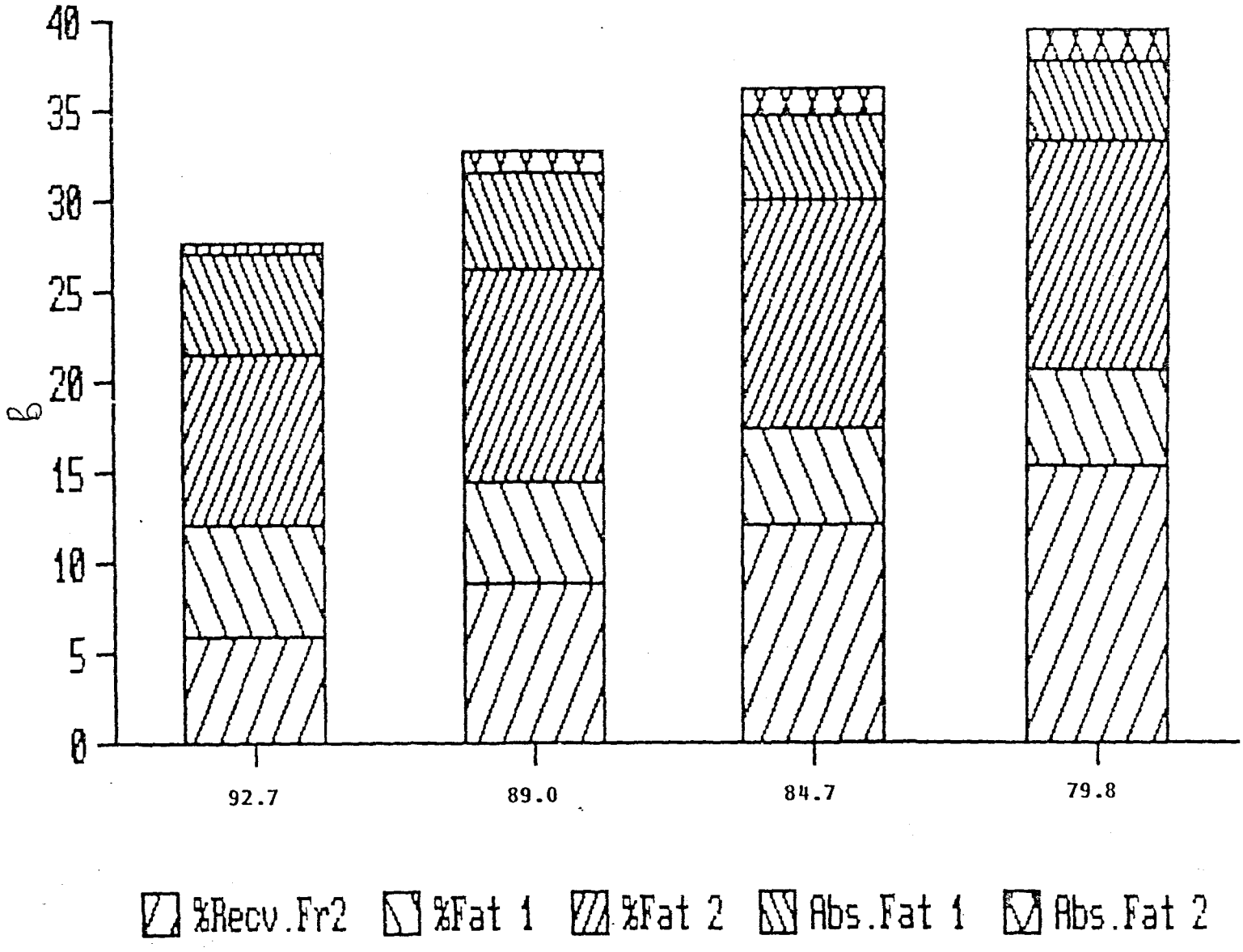


Fig 3b. Recovery and fat content of fractions of tempered grain (16%, 4h) milled by barley pearler

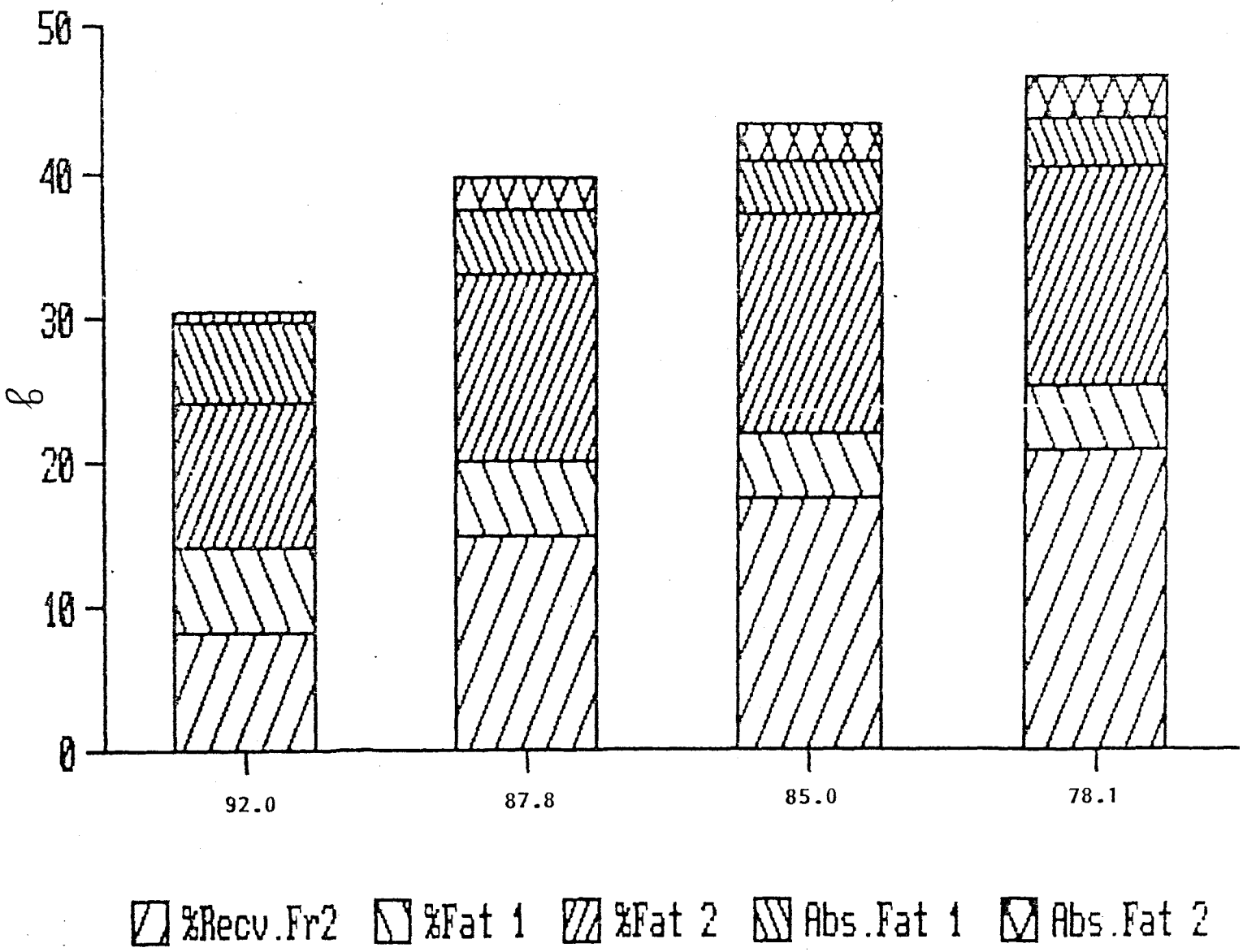


Fig 3c. Recovery and fat content of fractions of tempered grain (16%, 6h) milled by barley pearler

Table 4.2 : Effect of treatments on recovery and fat content of the fractions of pearl millet grain milled by barley pearler

Treatment	Treatment period (min)	Scouring Time (min)	Recovery (%)		Fat content			
			Fraction-I	Fraction-II	Fraction-I		Fraction-II	
					(%)	Absolute	(%)	Absolute
1	2	3	4	5	6	7	8	9
Blanching	3	2	94.0	5.50	6.21	5.84	9.42	0.52
		4	87.9	12.0	5.97	5.25	10.5	1.26
		6	84.0	15.5	5.65	4.75	11.2	1.74
		8	81.0	18.4	5.34	4.33	12.2	2.25
	6	2	92.0	7.57	6.10	5.61	9.58	0.73
		4	86.0	14.0	5.41	4.66	12.0	1.67
		6	83.2	16.8	4.49	3.74	14.6	2.45
		8	82.0	19.6	4.21	3.45	14.7	2.88
	9	2	91.1	8.07	5.98	5.50	10.1	0.82
		4	85.0	14.8	5.26	4.47	13.1	1.94
		6	82.0	17.9	4.42	3.71	14.9	2.67
		8	79.0	20.8	4.32	3.41	15.0	3.12
Acid (0.2N HCl) steeping for 6h and blanching	3	2	94.0	6.03	6.06	5.70	9.45	0.57
		4	91.3	8.81	5.79	5.29	11.7	1.02
		6	87.8	12.0	5.51	4.84	12.6	1.51
		8	84.4	15.4	5.18	4.37	12.8	1.97

Contd.....

Table 4.2 Contd.....

1	2	3	4	5	6	7	8	9
	6	2	94.0	5.60	6.09	5.82	9.79	0.56
		4	91.0	8.70	5.45	4.96	12.8	1.13
		6	87.7	12.0	4.97	4.36	14.5	1.74
		8	83.0	15.6	4.57	4.79	15.0	2.33
	9	2	92.7	7.30	6.01	5.57	9.74	0.71
		4	90.0	9.66	5.49	4.94	13.4	1.30
		6	86.0	13.3	4.74	4.08	15.5	2.05
		8	82.0	17.7	4.39	3.60	16.4	2.88
Control		2	90.0	9.80	5.84	5.25	10.7	1.05
		4	86.5	13.1	5.26	4.55	13.4	1.76
		6	82.4	17.2	4.23	4.23	16.0	2.75
		8	77.4	22.1	3.87	3.00	15.8	3.50
Pooled CD (P/ 0.05)			1.98	1.15	0.21	0.27	0.24	0.16

Values are means of four determinatios.

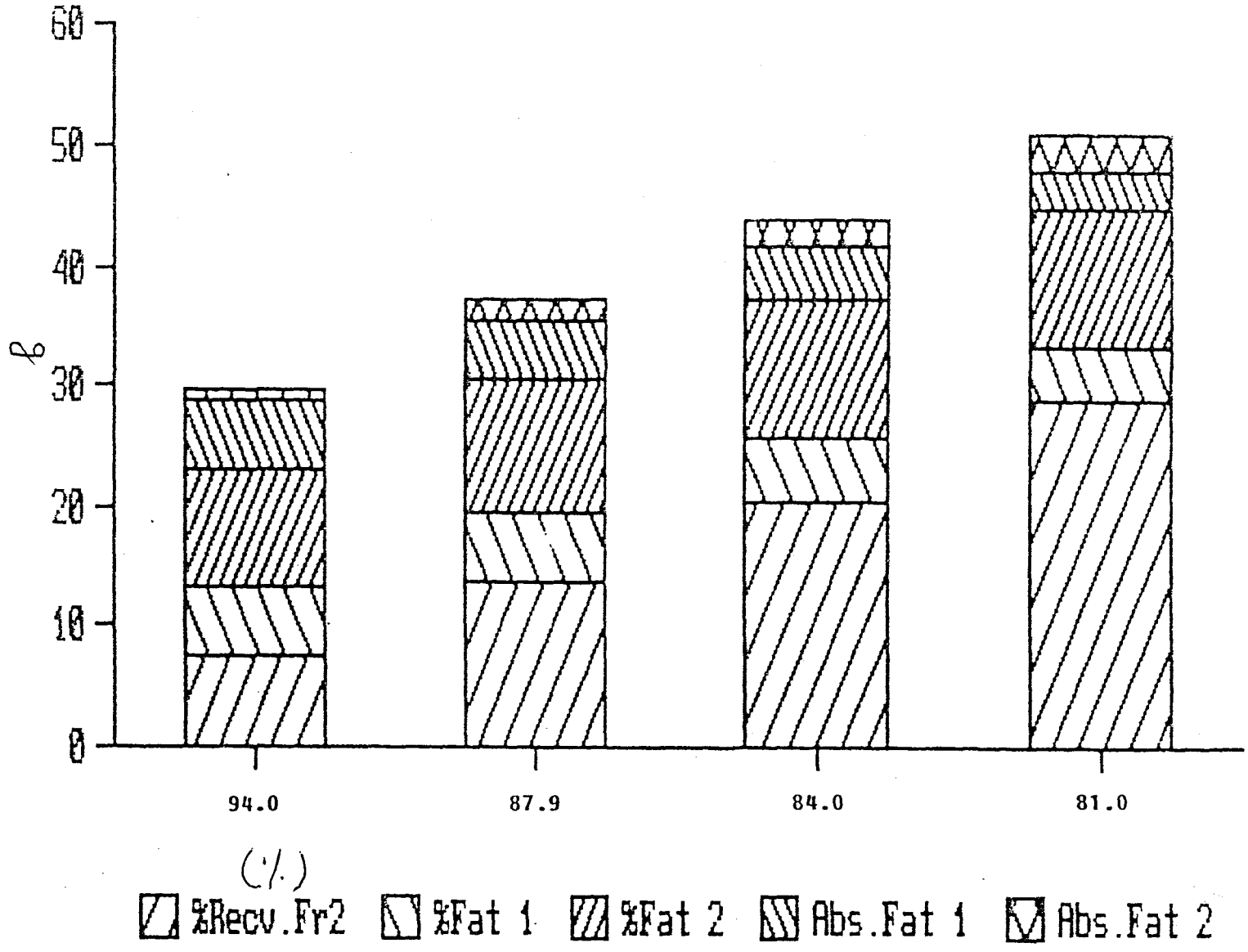


Fig 7a. Recovery and fat content of fractions of blanched grain (3 min) milled by barley pearler

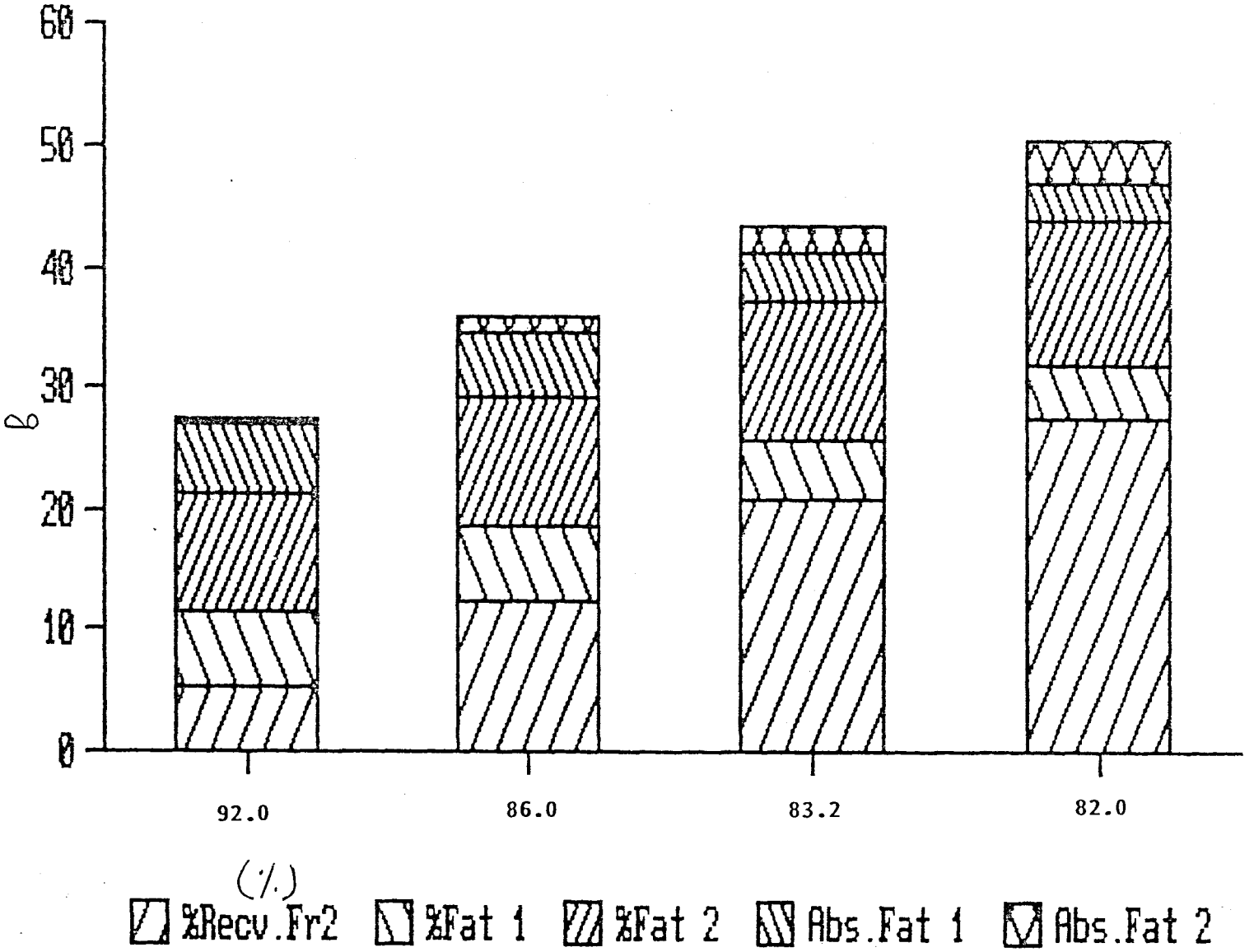


Fig 7b. Recovery and fat content of fractions of blanched grain (6 min) milled by barley pearler

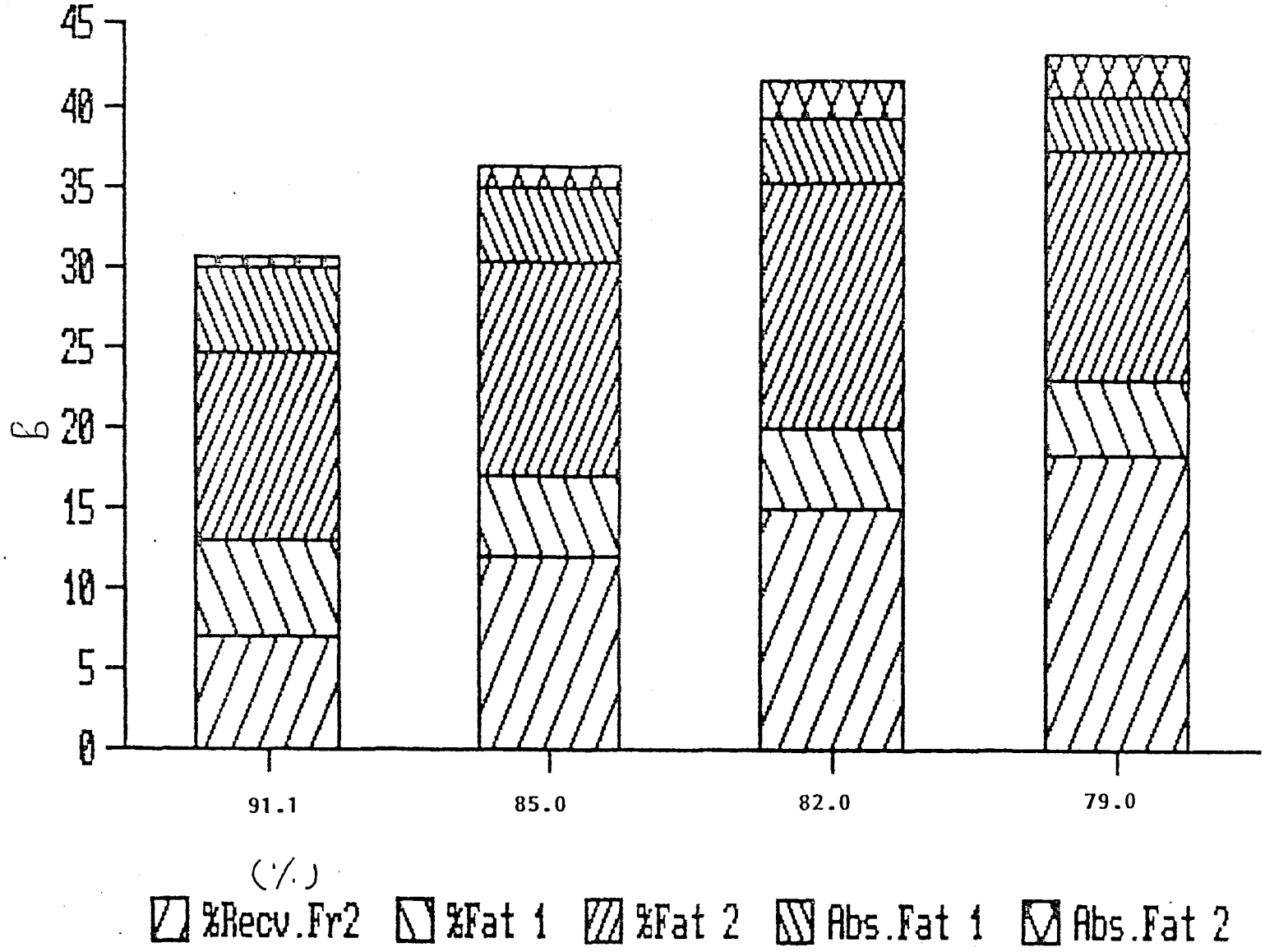


Fig 7c. Recovery and fat content of fractions of blanched grain (9 min) milled by barley pearler

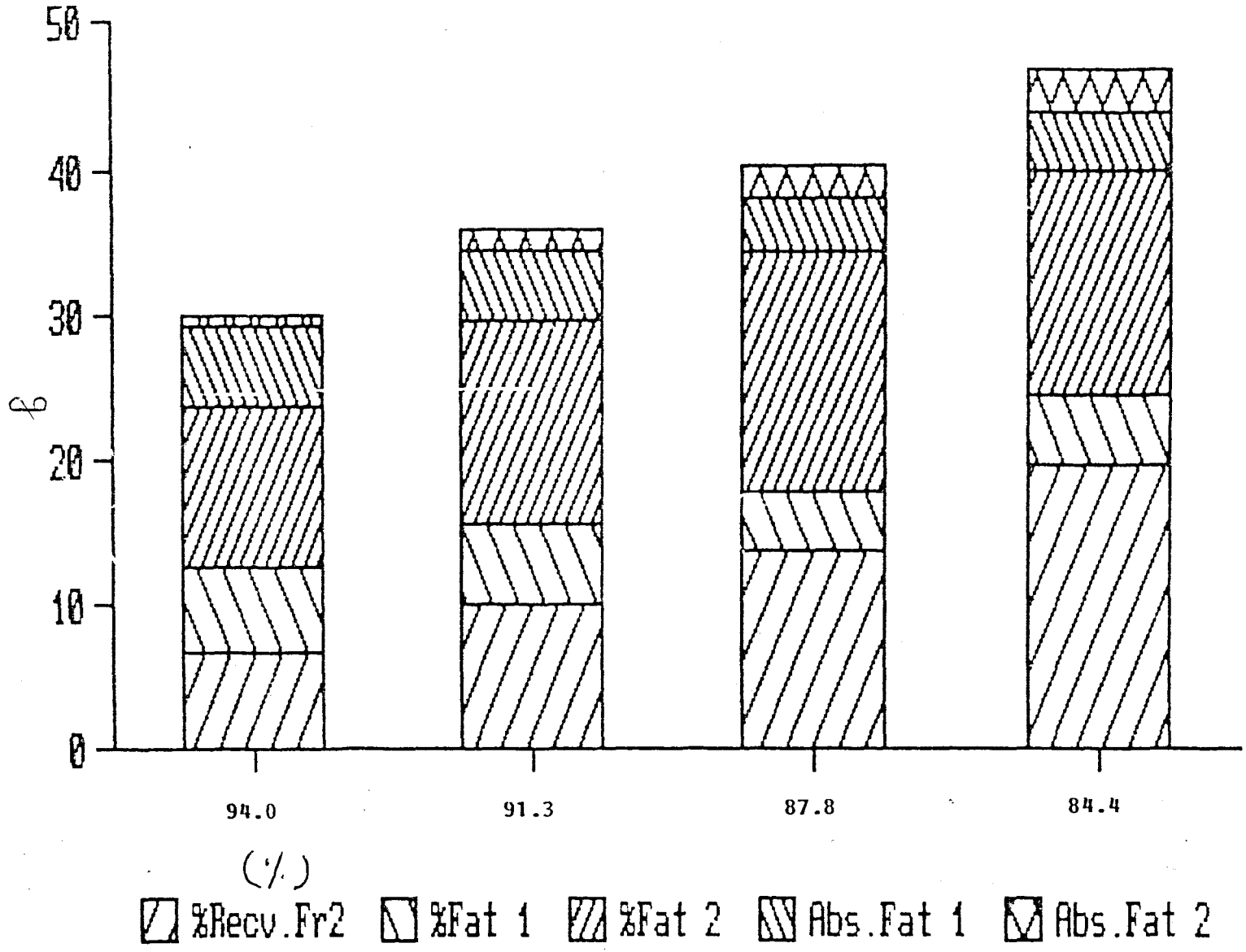


Fig 8a. Recovery and fat content of fractions of acid steeped and blanched (3 min) milled by barley pearler

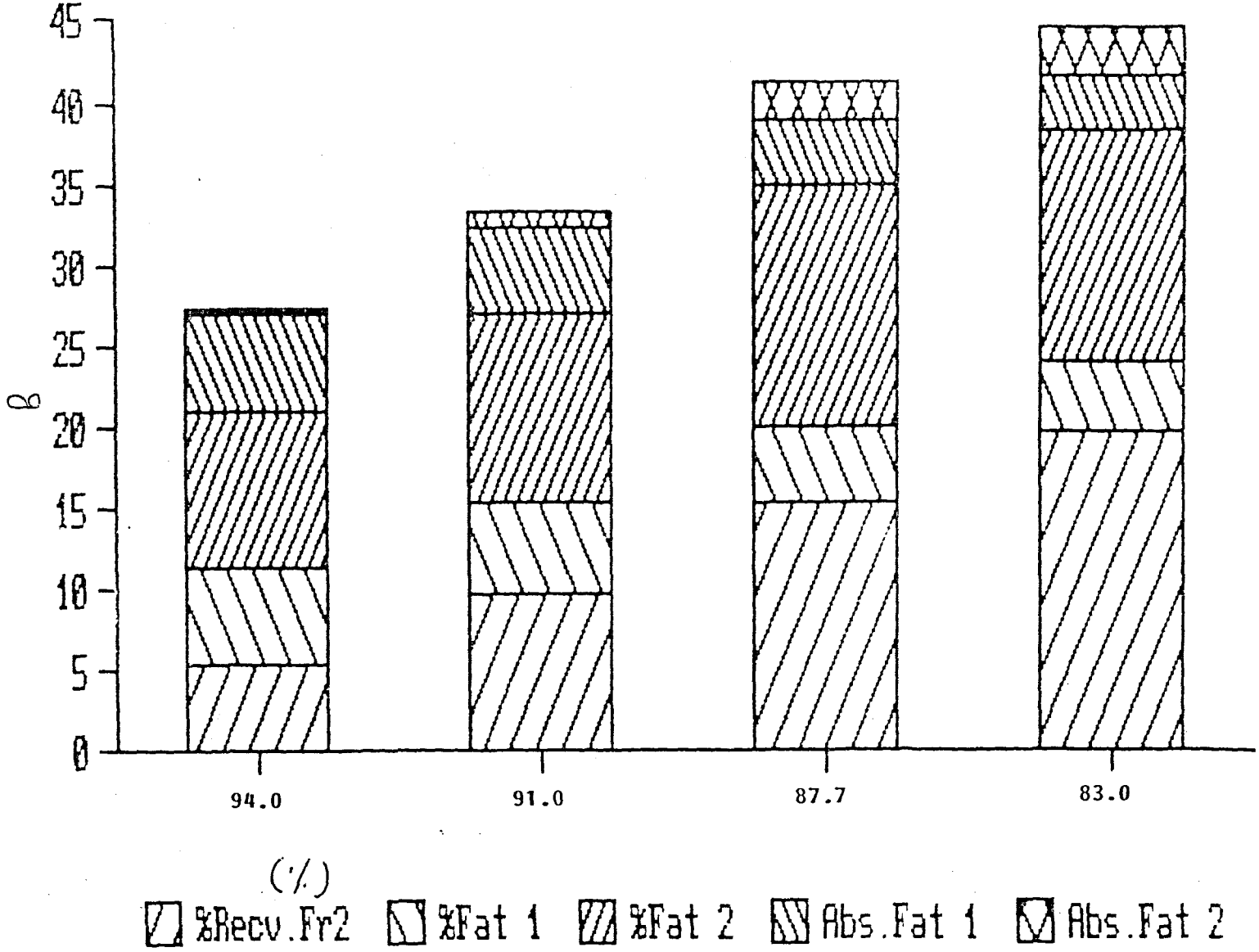


Fig 8b. Recovery and fat content of fractions of acid steeped and blanched (6 min) milled by barley pearler

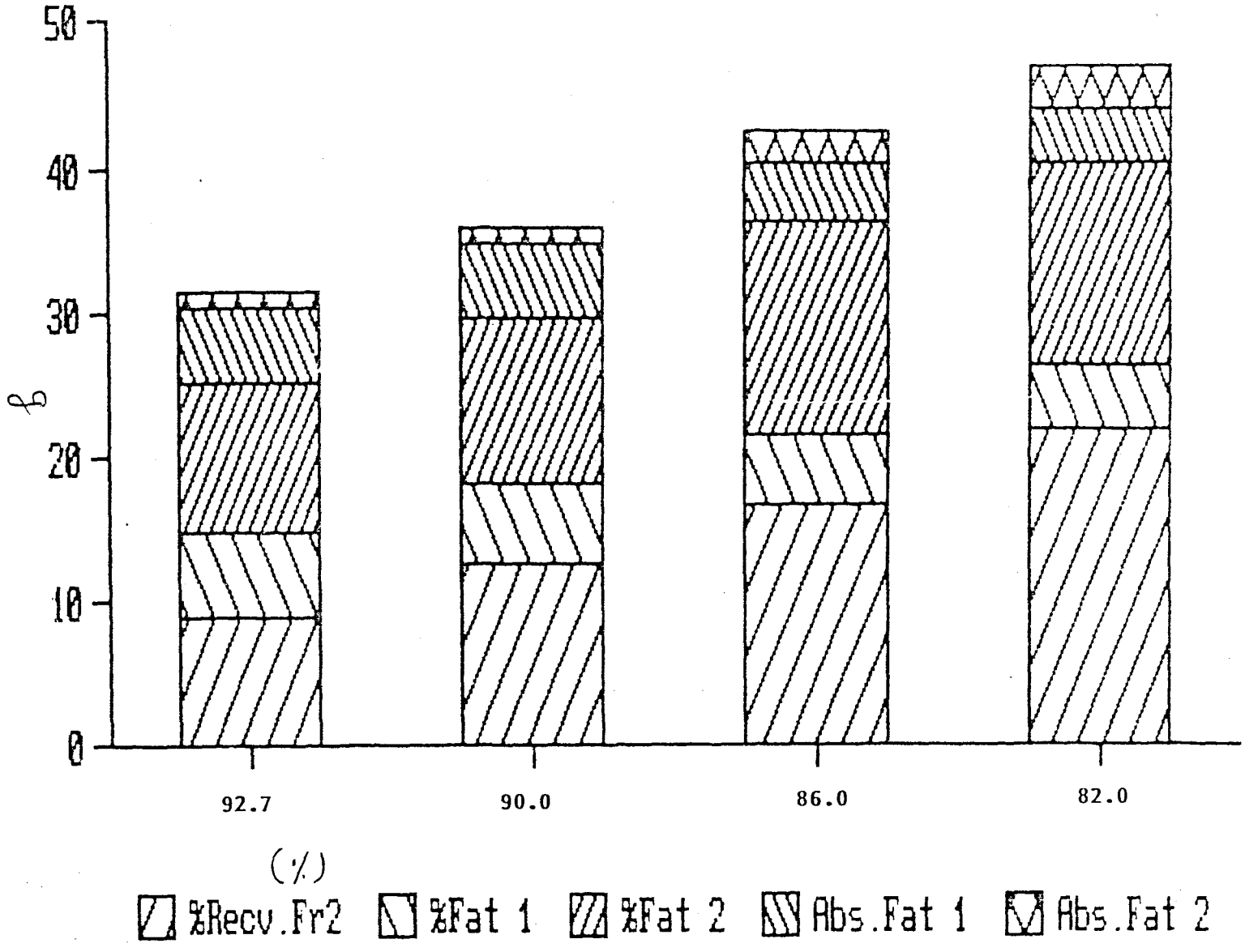


Fig 8c. Recovery and fat content of fractions of acid steeped and blanched (9 min) milled by barley pearler

The highest concentration of fat in fraction II i.e. 16.4 per cent was found when grains at 16 per cent moisture level were tempered for 4 h and milled in barley pearler for 6 min. Recovery of fraction I was also quite high i.e. 84.7 per cent (Table 4.1) Acid steeped (6 h) grains after blanching for 9 min and milled for 8 min yielded fraction II containing 16.4 per cent fat but the recovery of fraction I was relatively low i.e. 82 per cent (Table 4.2). Rest of the treatments did not seem to be better in comparison with untreated grains as six min milling of untreated grains gave 16 per cent fat in fraction II and recovery of corresponding fraction I was 82.4%. From the data in Tables 4.1 and 4.2 it can be generalised that fat content of fraction II was lowest at 2 min scouring time and increased with increasing scouring time. This implies that outer layers of pearl millet grain contains relatively higher concentration of fat. Fat content of fraction II may be further supplemented by removal of germ with successive increase in scouring time.

4.2.3 Rice Polishers

Milling by Satake rice polisher resulted in breakage of grains without removing bran and germ. Therefore, it was not used for further study.

McGill rice polisher gave more satisfactory results. Pearl millet grains were exposed to 1, 2, 3 and 4 min milling time and two fraction one representing endosperm and other containing most

of bran and germ were obtained. Their fat content was expressed as g/100 g and in absolute amount as g. In order to remove fat rich germ portion of pearl millet, the grains were tempered with moisture levels of 12, 14 and 16 per cent and were kept for 2, 4 and 6 h before milling. Other treatments included blanching of grains in boiling water for 3, 6 and 9 min and steeping of grains in 0.2N HCl for 6 h followed by blanching for 3, 6 and 9 min. Only steeping of grains for 3, 6 and 9 h resulted in excessive breakage of grains and hence the treatment not included for further study.

Per cent recovery of fraction I decreased and that of fraction II increased as milling time was increased from 1 to 4 min (Table 4.3). One min milling of untreated sample by rice polisher gave 89.1 per cent recovery of fraction I which on increasing the scouring time to 4 min was reduced to 71.6 per cent. Raising the scouring time from 1 to 4 min also increased the concentration of fat in fraction II whereas fat concentration in fraction I declined. Increase in the moisture level from 12 to 14 per cent tempering decreased the yield (%) of fraction I significantly (Table 4.3). The recovery moved upward following an increase in moisture level to 16 per cent. A rise in moisture level from 12 to 16 per cent resulted in decrease of fat contents in fraction I and increase of that in fraction II (Fig 4-6,9 & 10) Per cent recovery and fat of fraction decreased following an increase in tempering period at every moisture level. Blanching, both after steeping or without steeping did not

Table 4.3 : Effect of tempering on recovery and fat content of the fractions of pearl millet grain milled by rice polisher

Tempering moisture level(%)	Tempering period (h)	Scoring Time (min)	Recovery (%)		Fat content			
			Fraction-I	Fraction-II	Fraction-I		Fraction-II	
					(%)	Absolute	(%)	Absolute
1	2	3	4	5	6	7	8	9
12	2	1	94.0	5.45	6.20	5.83	9.40	0.51
		2	87.2	12.6	6.01	5.24	10.7	1.33
		3	79.0	20.6	5.05	4.00	11.4	2.35
		4	71.7	27.1	4.42	3.07	12.0	3.30
	4	1	92.0	7.33	6.09	5.61	9.80	0.72
		2	86.0	13.7	5.87	5.05	11.0	1.52
		3	78.8	20.5	5.04	3.97	11.8	2.42
		4	70.2	29.6	4.26	2.98	11.4	3.37
	6	1	92.0	7.42	6.08	5.56	9.70	0.73
		2	85.5	14.1	5.81	4.97	10.6	1.50
		3	72.0	27.6	4.50	3.25	12.0	3.31
		4	64.5	37.4	4.25	2.72	10.5	3.89
14	2	1	90.0	9.42	5.82	5.24	10.8	1.02
		2	80.0	19.6	5.16	3.92	11.0	2.16
		3	70.1	29.0	3.84	2.69	12.4	3.60
		4	65.0	34.1	3.56	2.31	10.3	3.40
	4	1	92.0	7.80	5.88	5.41	10.8	0.84
		2	78.0	21.4	5.20	4.06	11.0	2.35
		3	71.3	29.1	3.32	2.37	11.4	3.90
		4	67.1	33.2	3.47	2.32	11.8	3.92

Contd.....

Table 4.3 Contd.....

1	2	3	4	5	6	7	8	9
	6	1	89.0	10.1	5.80	5.23	10.0	1.02
		2	77.1	23.5	5.31	4.10	10.5	2.47
		3	68.8	31.0	3.40	2.35	13.1	4.06
		4	61.7	38.4	3.40	2.10	10.5	4.02
16	2	1	90.2	9.42	5.74	5.20	11.0	1.03
		2	85.0	14.6	4.80	4.10	12.5	1.82
		3	73.5	26.4	3.46	2.54	13.9	3.67
		4	65.6	33.4	3.20	2.10	12.6	
	4	1	92.0	7.70	5.80	5.34	11.5	0.68
		2	85.0	14.5	4.91	4.24	11.5	1.67
		3	72.0	27.8	3.43	2.47	14.0	3.89
		4	65.1	35.4	3.24	2.12	12.5	4.25
	6	1	87.2	11.7	5.75	5.01	10.6	1.24
		2	82.4	17.5	5.20	4.29	11.1	1.94
		3	71.2	28.0	3.32	2.37	14.0	3.93
		4	62.0	37.9	3.24		11.6	4.41
Control		1	89.1	10.4	5.72	5.09	11.4	1.19
		2	84.2	15.6	4.98	4.19	13.7	2.14
		3	80.5	19.8	3.85	3.10	16.1	3.14
		4	71.6	28.0	3.18	2.28	14.6	4.07
Pooled CD (P / 0.05)			2.06	1.34	0.32	0.12	0.24	0.34

Values are means of four determinations.

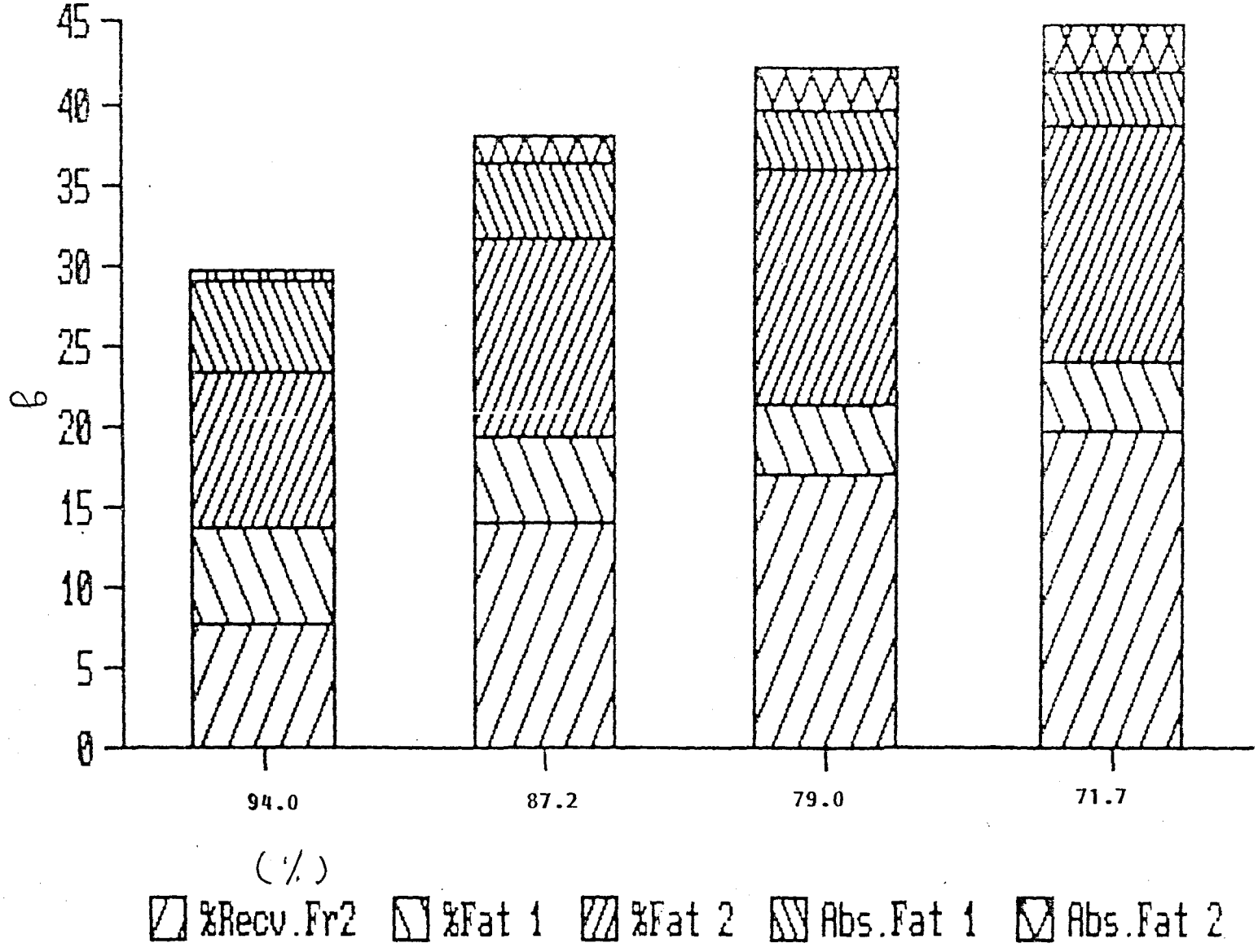


Fig 4a. Recovery and fat content of fractions of tempered grain (12%, 2h) milled by rice polisher

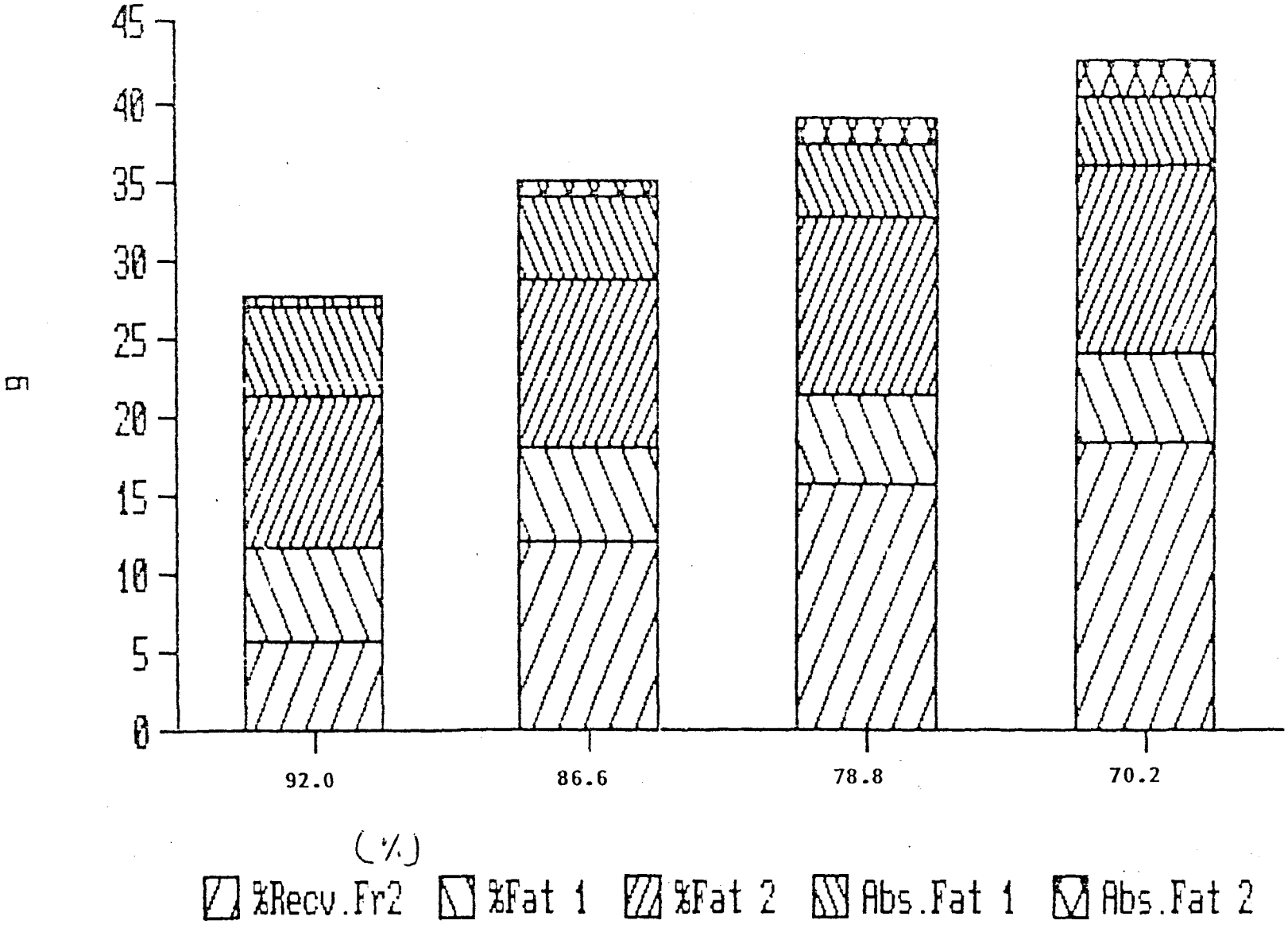


Fig 4b. Recovery and fat content of fractions of tempered grain (12%, 4h) milled by rice polisher

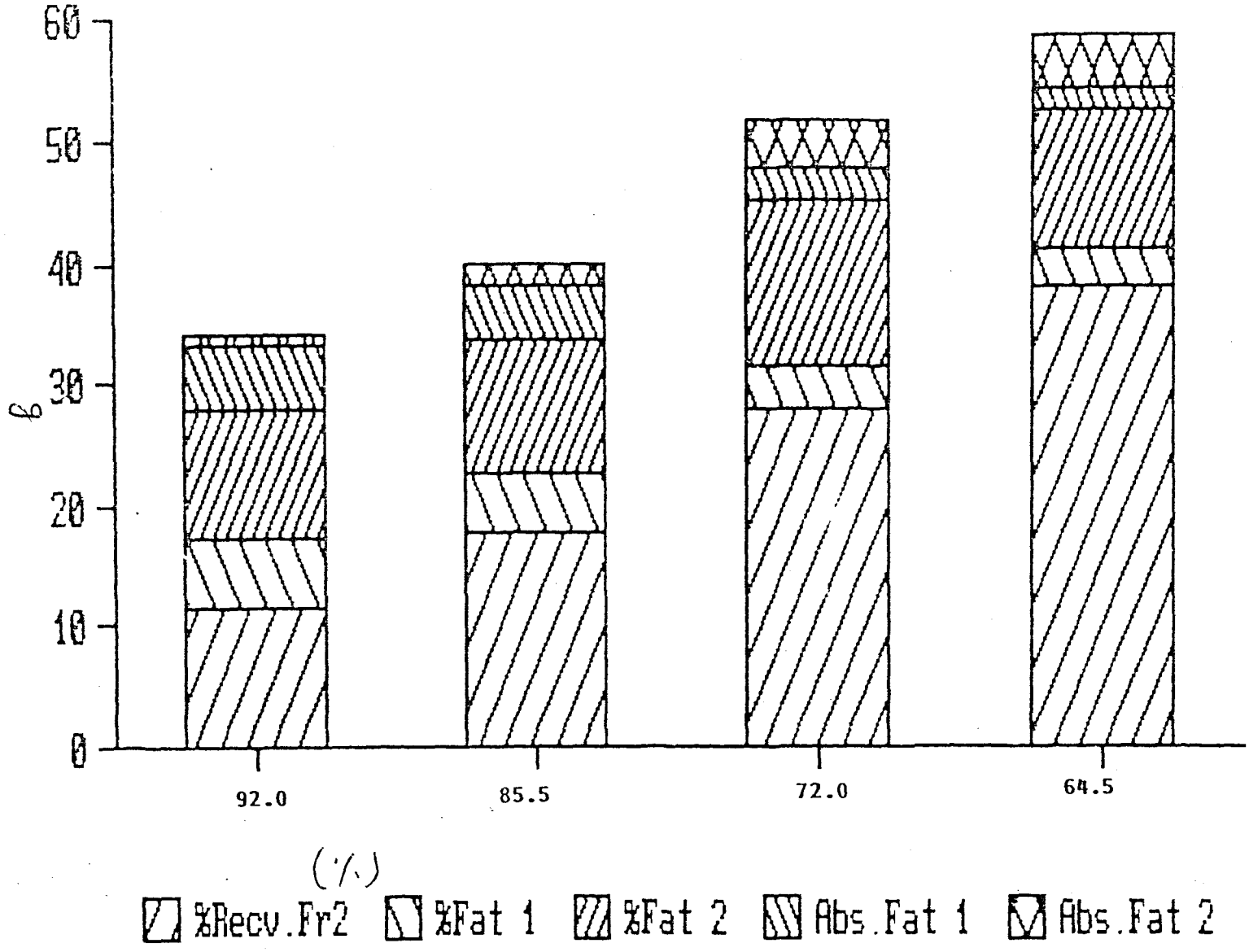


Fig 4c. Recovery and fat content of fractions of tempered grain (12%, 6h) milled by rice polisher

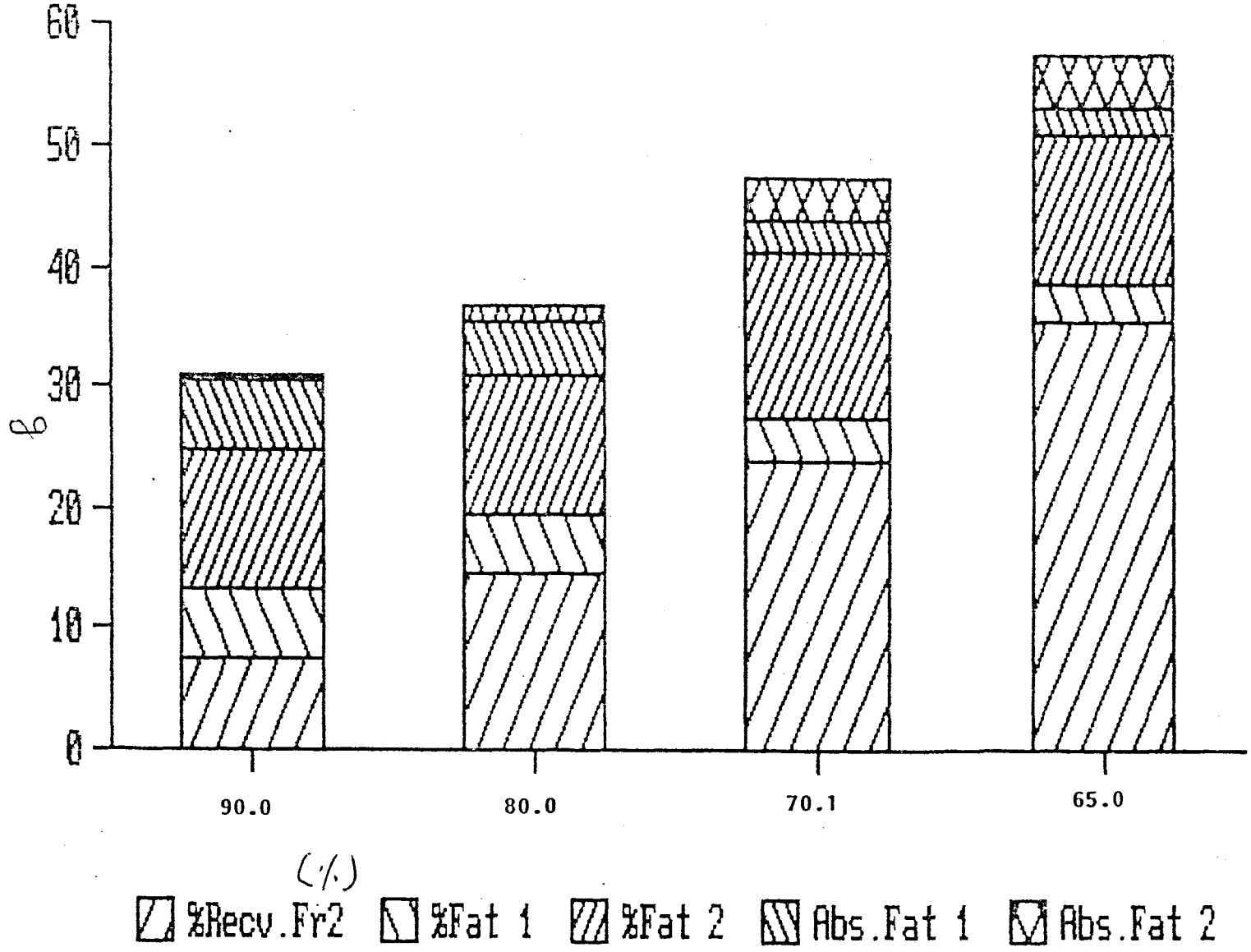


Fig 5a. Recovery and fat content of fractions of tempered grain (14%, 2h) milled by rice polisher

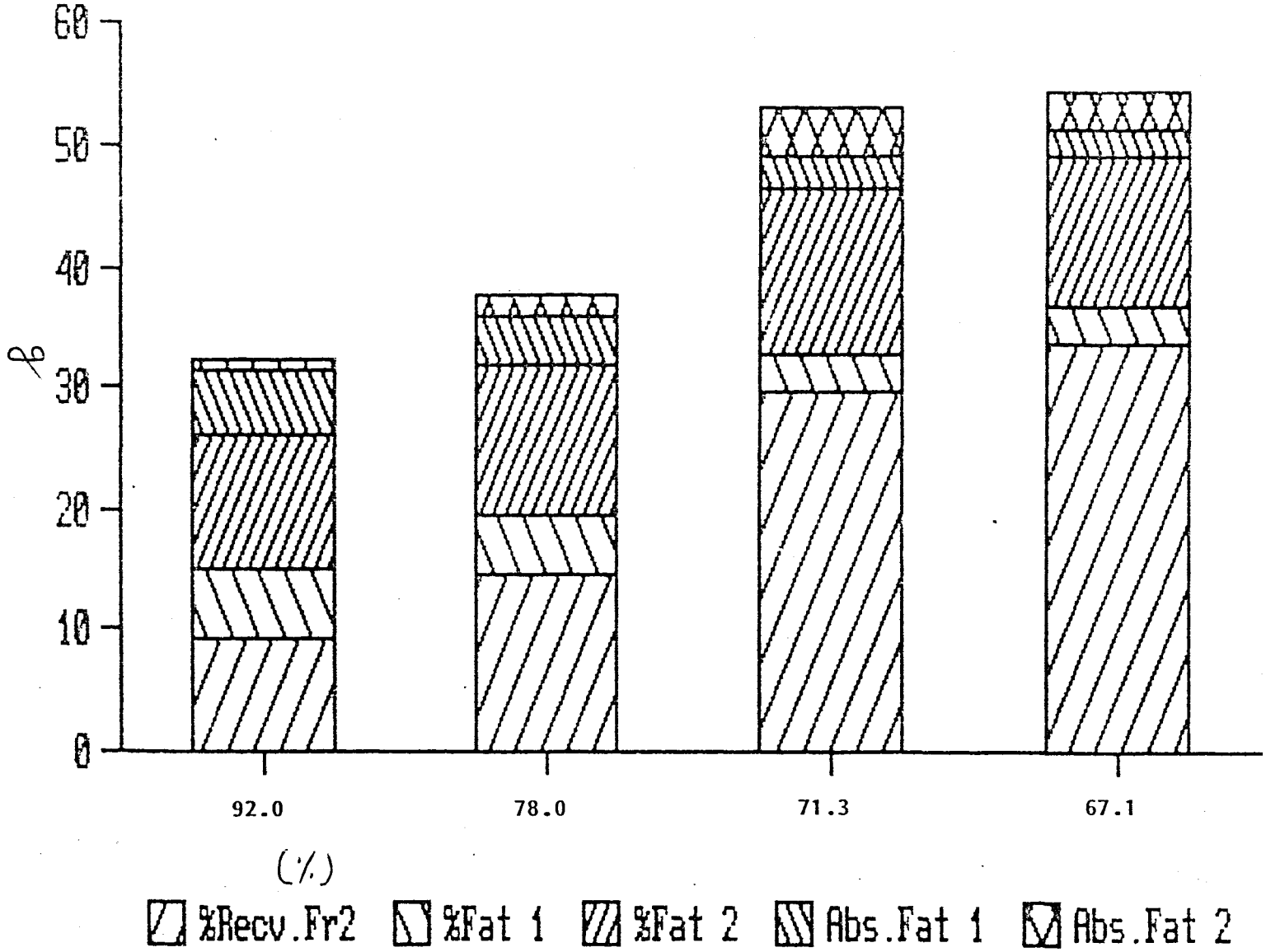


Fig 5b. Recovery and fat content of fractions of tempered grain (14%, 4h) milled by rice polisher

Fig 5c. Recovery and fat content of fractions of tempered grain (14%, 6h) milled by rice polisher

Fig 6a. Recovery and fat content of fractions of tempered grain (16%, 2h) milled by rice polisher

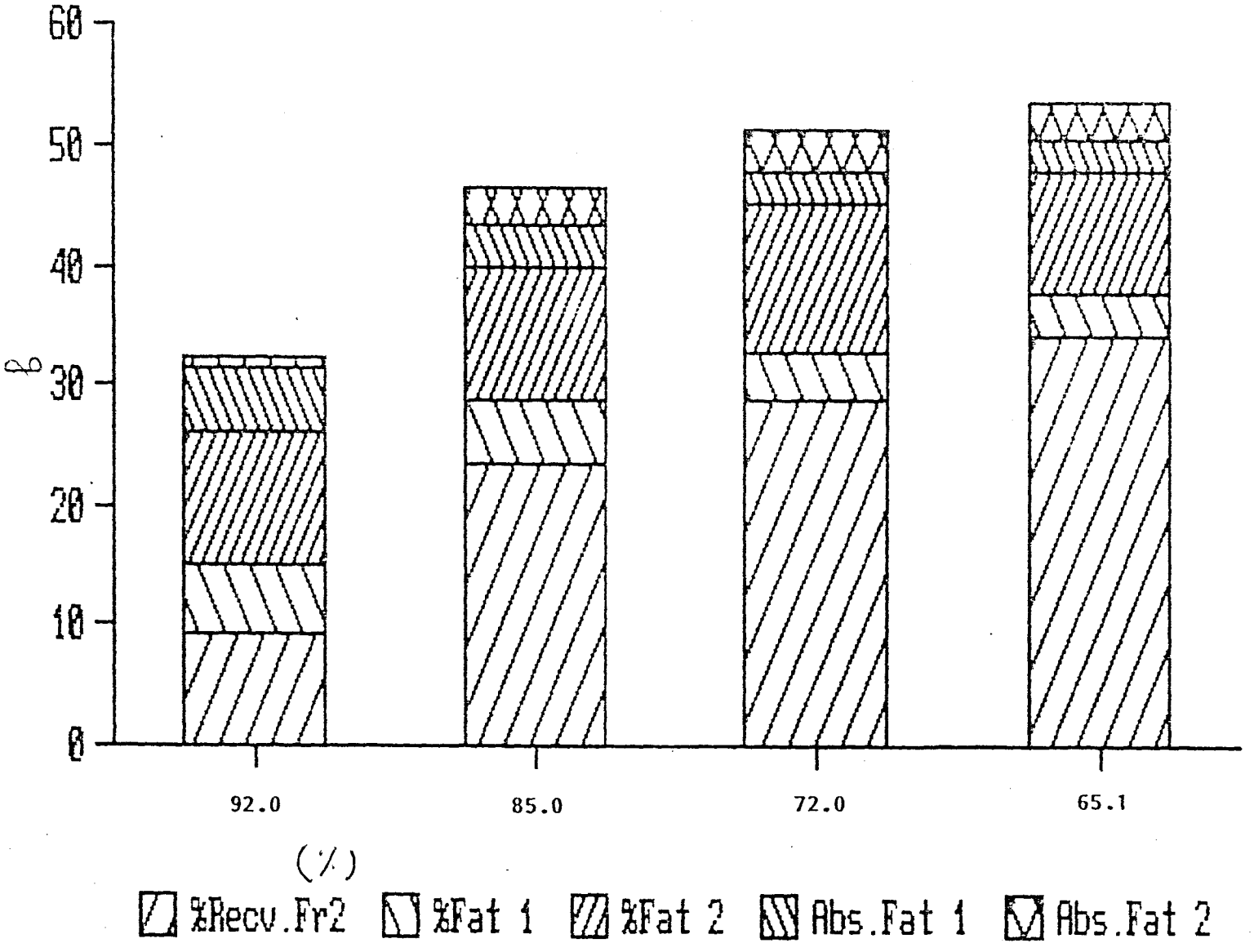


Fig 6b. Recovery and fat content of fractions of tempered grain (16%, 4h) milled by rice polisher

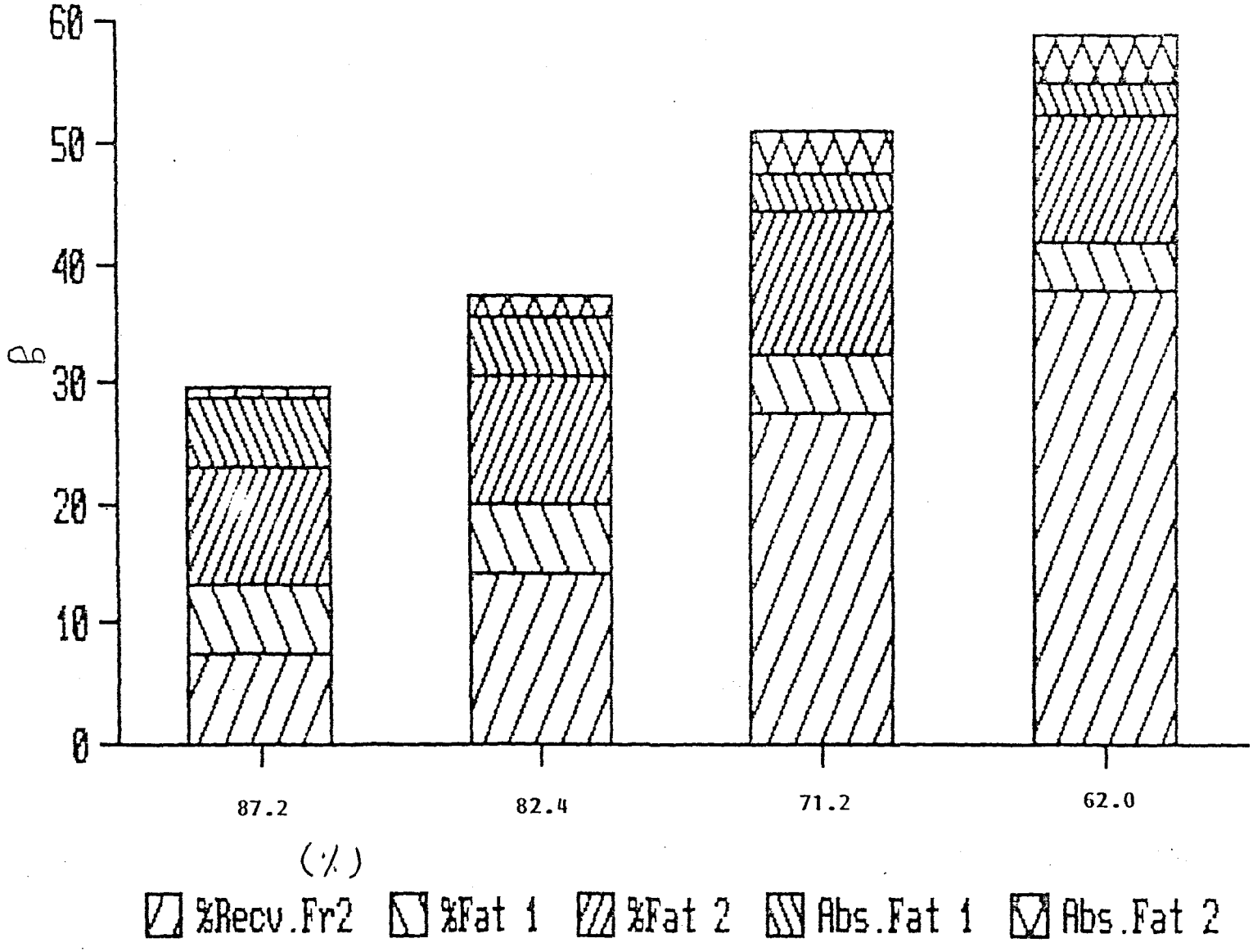


Fig 6c. Recovery and fat content of fractions of tempered grain (16%, 6h) milled by rice polisher

change the trend of recovery and fat content (per cent) of milled fractions. Percent yield of fraction I decreased and that of fraction II increased when blanching time was raised from 3 to 6 min (Table 4.1). Highest concentration of fat in fraction II was observed after 9 min blanching and 3 min milling (Table 4.4).

Steeping in 0.2N HCl followed by blanching improved the per cent yield of fraction I (Table 4.4). Higher concentration of 18.4 per cent fat in fraction II was recovered after 9 min blanching and 4 min scouring of acid steeped grains and steeping followed by blanching resulted in more removal of fat rich portion from pearl millet grains. With increase in scouring time, fat concentration in fraction II kept on increasing.

On the basis of fat content of fraction II and recovery of fraction I (Tables 4.1 and 4.2) the treatments including tempering at 16 per cent moisture level for 4 h, blanching for 6 and 9 min, steeping in 0.2N HCl (6 h) followed by blanching were selected for further study of barley pearler milling. One untreated group was taken as control. Fraction I and II recovered from the grains after treatment as mentioned above as well as untreated grains as given in Table 4. 5 were used for further study. Recovery of fractions I and II after a varied milling time of 6-7 min ranged from 82.3 to 90.4 and 9.4 to 17.3 per cent, respectively.

Similarly in the rice polisher millet grains after these treatments; 9 min blanching, steeping in 0.2N HCl for 6 h followed

Table 4.4 : Effect of treatments on recovery and fat contents of the fractions of pearl millet grain milled by rice polisher

Treatment	Treatment period (min)	Scouring time (min)	Recovery (%)		Fat content			
			Fraction-I	Fraction-II	Fraction-I		Fraction-II	
					(%)	Absolute	(%)	Absolute
1	2	3	4	5	6	7	8	9
Blanching	3	1	93.7	6.03	6.17	5.78	9.05	0.55
		2	89.7	9.78	5.70	5.11	10.6	1.04
		3	82.0	17.6	5.00	4.10	12.3	2.17
		4	79.0	20.2	4.78	3.78	12.4	2.48
	6	1	92.0	7.72	5.98	5.50	9.28	0.72
		2	85.9	13.8	5.49	4.72	11.3	1.56
		3	80.0	19.8	4.39	3.52	13.5	2.63
		4	76.0	23.1	4.40	3.35	12.7	2.92
	9	1	91.0	8.80	5.81	5.29	9.70	0.84
		2	84.0	16.0	5.00	4.21	12.9	2.07
		3	77.9	22.0	3.90	3.02	14.2	3.12
		4	72.0	27.9	3.67	2.64	13.9	3.87
Acid (0.2N HCl) steeping for 6h and blanching	3	1	95.0	5.00	5.83	5.45	11.0	0.55
		2	92.0	7.75	5.69	5.22	13.0	1.01
		3	87.8	11.5	5.02	4.40	14.7	1.69
		4	84.6	15.1	4.72	4.00	14.8	2.22

Contd.....

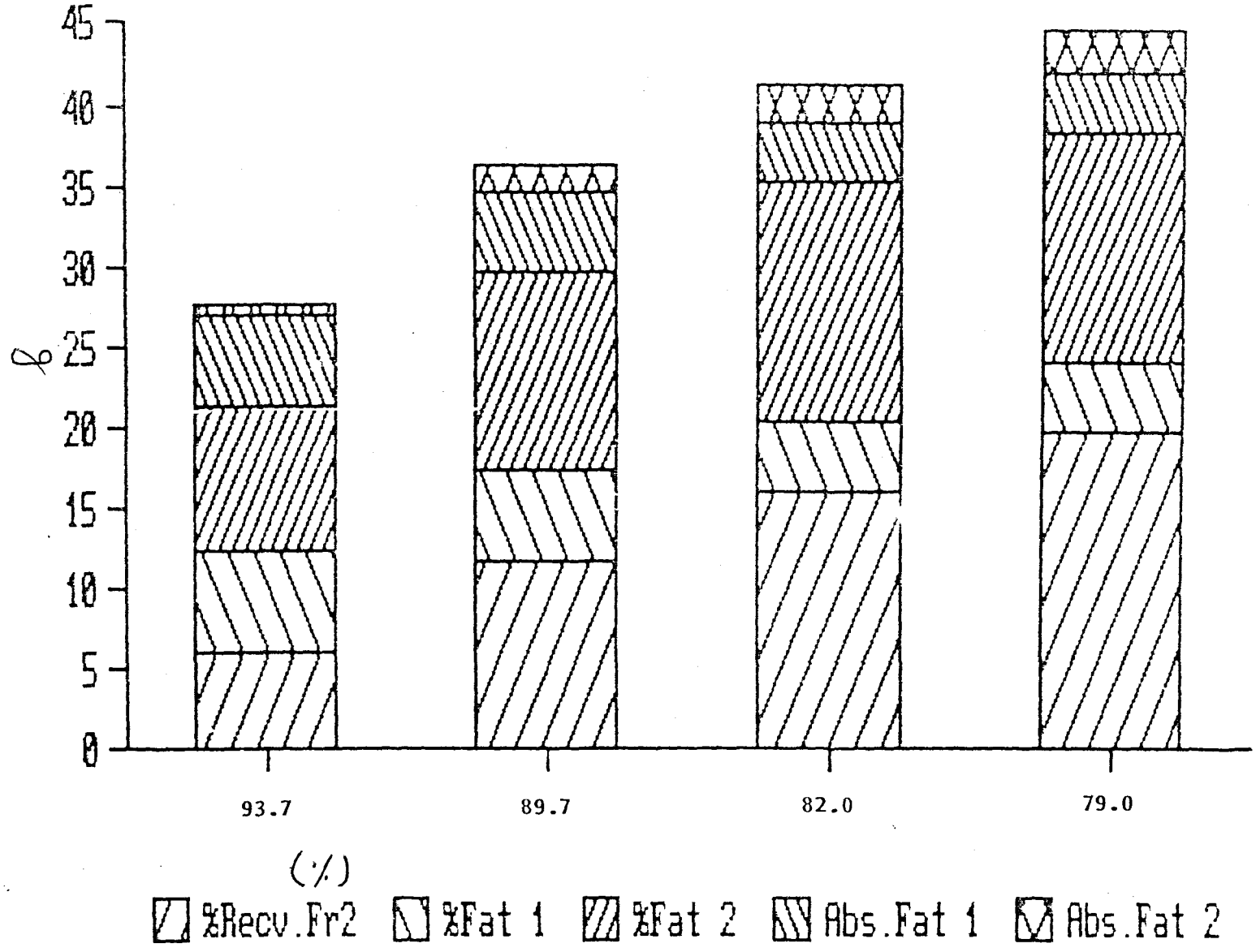


Fig 9a. Recovery and fat content of fractions of blanched grain (3 min) milled by rice polisher

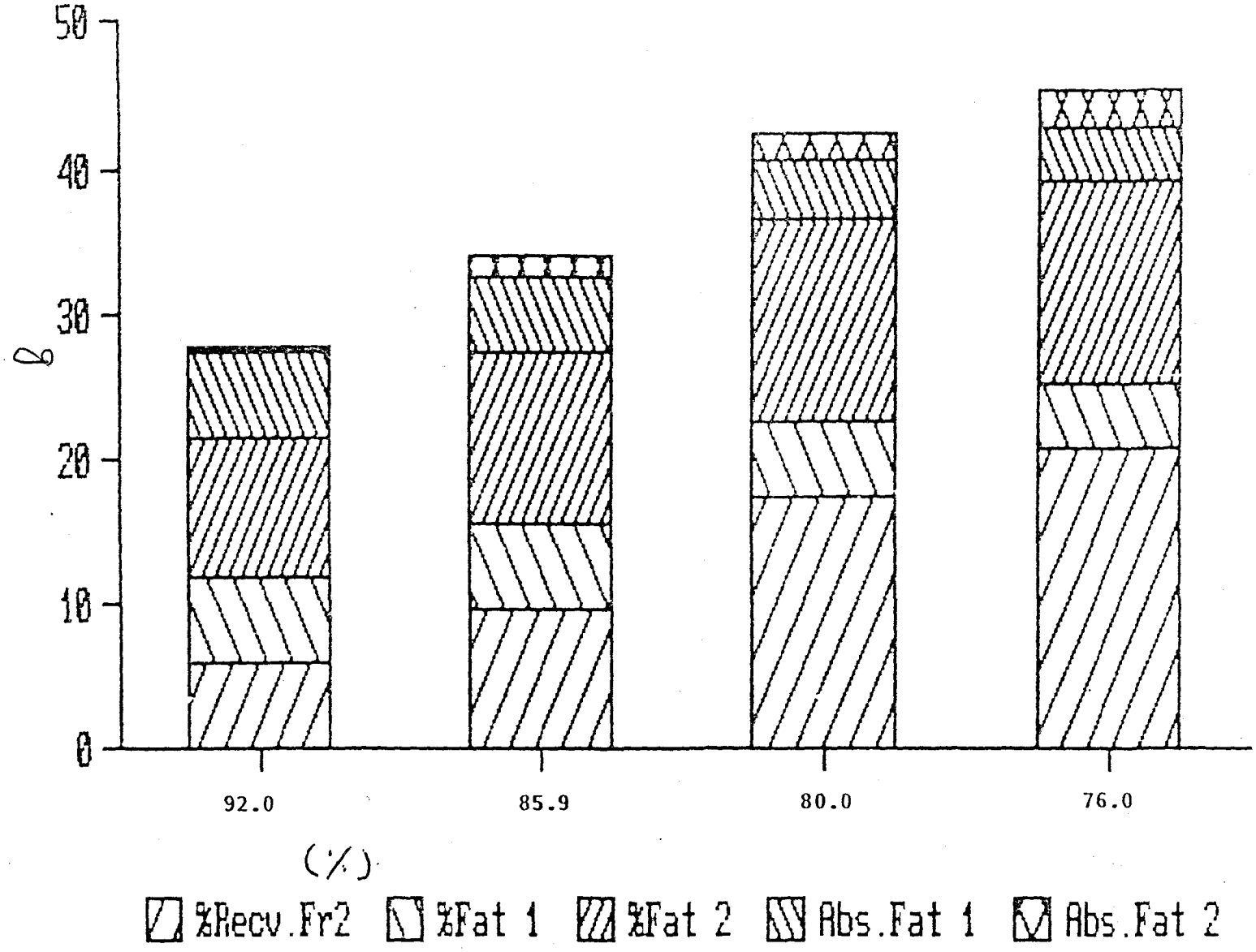


Fig 9b. Recovery and fat content of fractions of blanched grain (6 min) milled by rice polisher

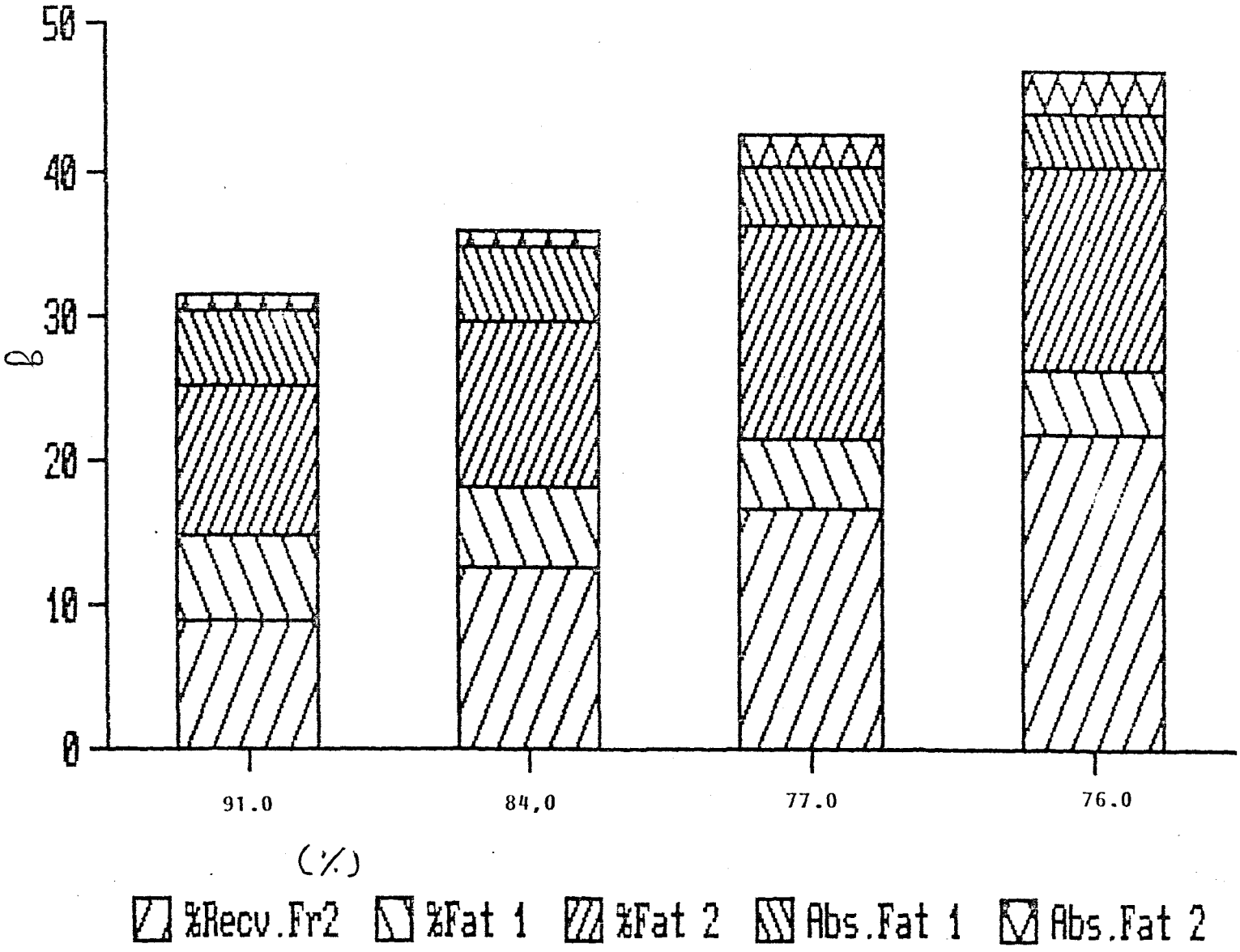


Fig 9c. Recovery and fat content of fractions of blanched grain (9 min) milled by rice polisher

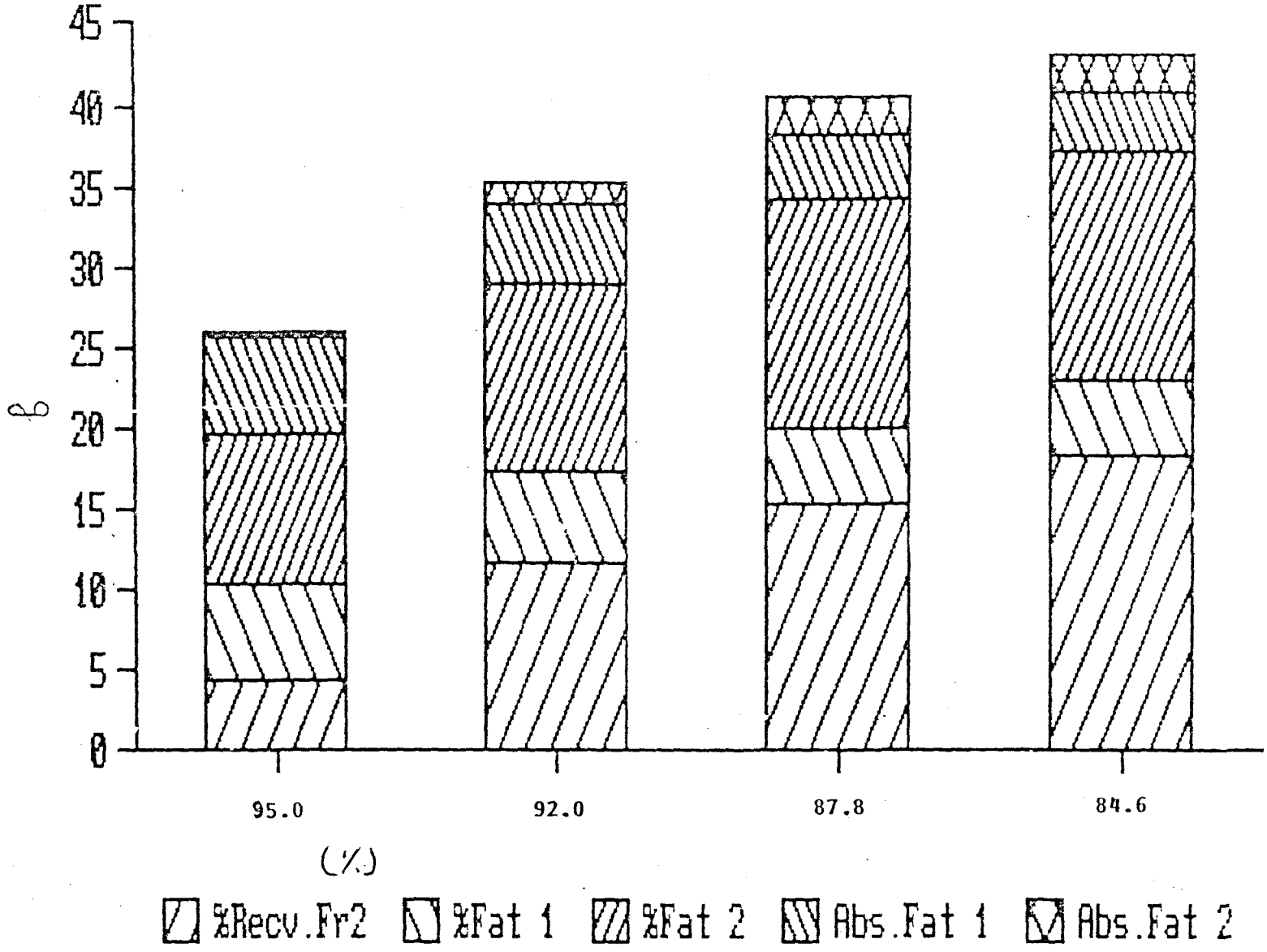


Fig 10a. Recovery and fat content of fractions of acid steeped and blanched grain (3 min) milled by rice polisher

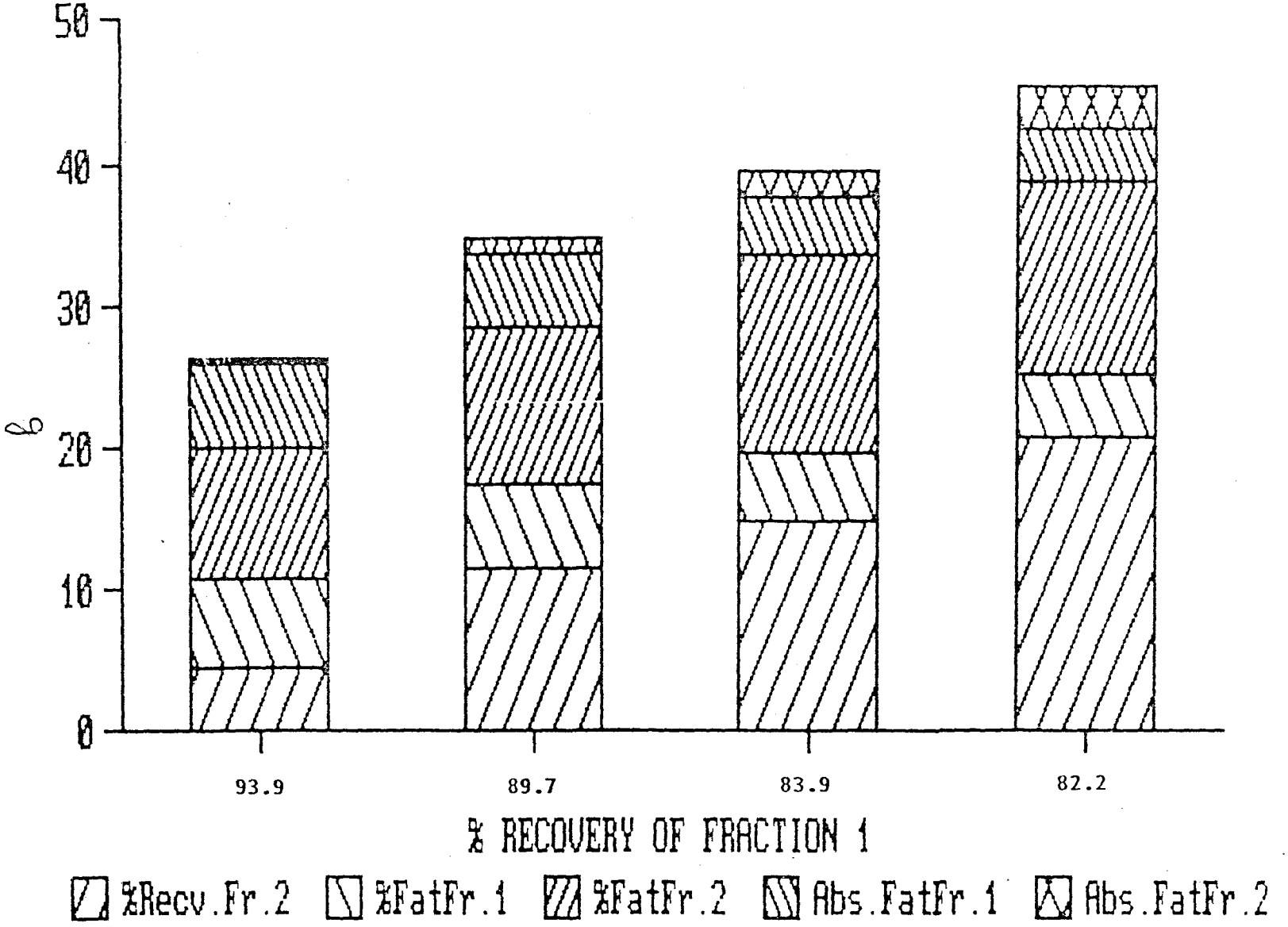


Fig 10b. Recovery and fat content of fractions of acid steeped and blanched grain (6 min) milled by rice polisher

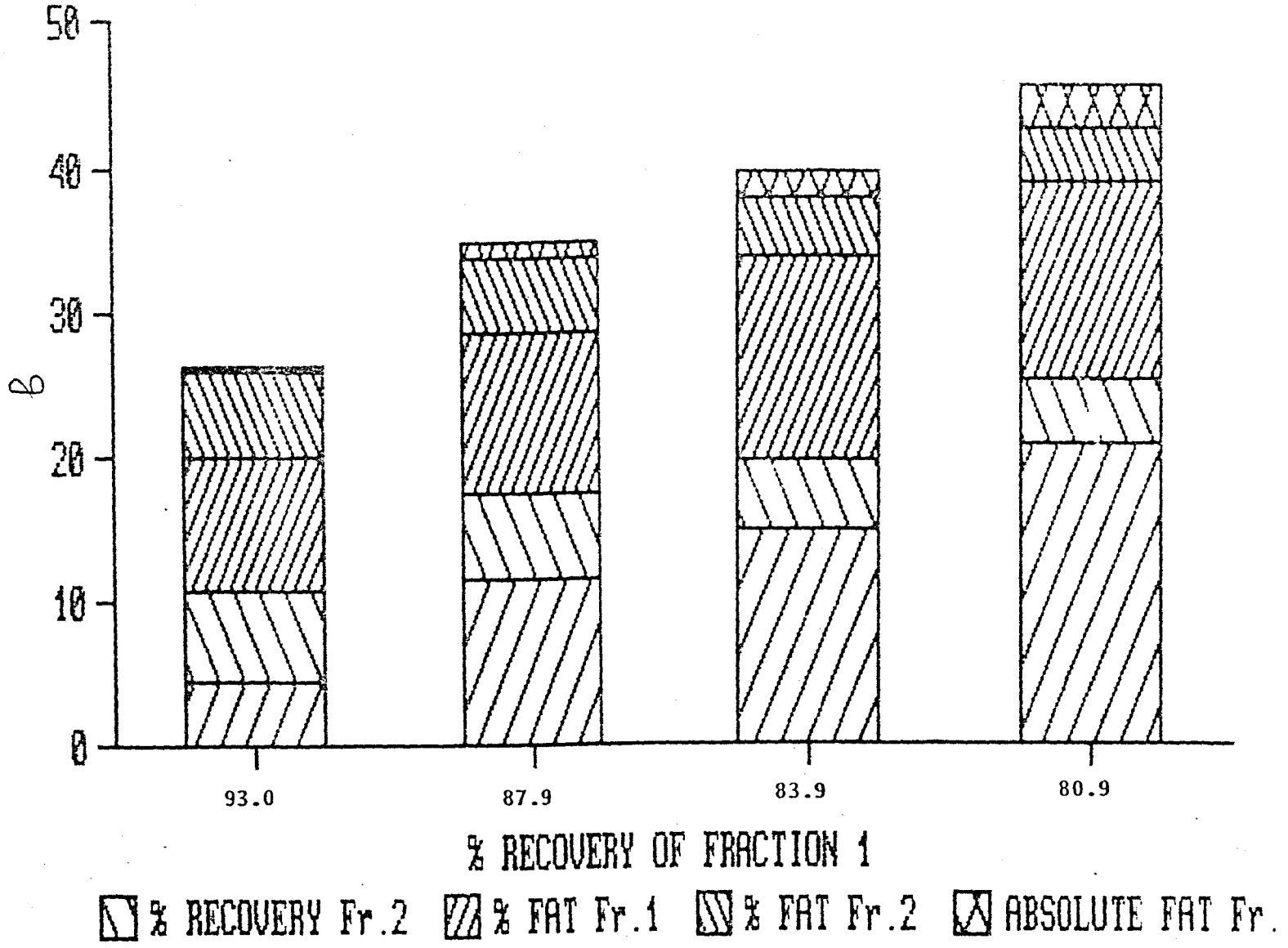


Fig 10c. Recovery and fat content of fractions of acid steeped and blanched grain (9 min) milled by rice polisher

Table 4.4 Contd.....

1	2	3	4	5	6	7	8	9
	6	1	93.9	4.60	5.70	5.39	11.8	0.65
		2	89.7	9.80	5.29	4.75	14.8	1.45
		3	83.9	15.7	4.48	3.76	15.3	2.40
		4	82.2	17.6	4.10	3.37	16.5	2.90
	9	1	93.0	7.01	5.64	5.25	12.1	2.87
		2	87.9	11.7	5.03	4.42	15.8	1.84
		3	83.9	15.4	3.86	3.23	17.6	2.67
		4	80.9	18.8	3.62	2.92	18.4	3.46
Control		1	89.1	10.4	5.72	5.09	11.4	1.19
		2	84.2	15.6	4.98	4.19	13.7	2.14
		3	80.5	19.8	3.85	3.10	16.1	3.14
		4	71.6	28.0	3.18	2.28	14.6	4.07
Pooled CD (P / 0.05)			1.78	1.06	0.32	0.30	0.29	0.21

Values are means of four determinations.

Table 4.5 : Recovery of the fractions of treated pearl millet grains milled by barley pearler

Treatment	Scouring time (min)	Recovery (%)	
		Fraction-I	Fraction-II
Tempering at 16% moisture level 4h	7	86.1±0.68	13.5±0.72
Blanching (6 min)	7	85.0±0.88	14.7±0.52
Blanching (9 min)	7	84.1±0.33	15.5±0.42
Acid (0.2N HCl) steeping for 6h and blanching (9 min)	6	85.4±0.58	14.3±0.57
Alkali [0.5% $Ca(OH)_2$] steeping for 6h and blanching (9 min)	7	90.4±0.84	9.37±0.50
Without treatment	6	82.3±0.38	17.3±0.41
CD (P / 0.05)		0.64	0.48

Values are means ± SD of six determinations.

by 9 min blanching, tempering at 14 per cent moisture level for 4 h conditioning period and tempering at 16 per cent moisture level for 2, 4 and 6 h tempering period, were milled for 3 min. The recovery of fraction I and fraction II varied from 70.5 to 88.2 and 11.3 to 28.8 per cent, respectively (Table 4.6). Both these fractions were further used for nutritional evaluation, storability and product development. Kurien and Desikachar (1962) also found that moistening finger millet with 3-7 per cent water for about 2 h, followed by grinding in a Wiley Mill produced fractions high inhusk; steaming of grains with 5 per cent extra water with initial moisture of 11 per cent produced maximum yield. Reichert and Young(1976) studied the comparative dehulling quality of traditional pestle and mortar method, Strong Scott barley pearler, Palyi compact milling system (attretion type) and Hill grain thresher (abrasive type) and reported that barley pearler and Hill grain thresher were superior to Palyi compact milling system. Abdelrehman et al. (1983) decorticaed pearl millet grain by tempering at 22 per cent moisture level and single-pass milling on finely corrugated rolls. The germ was more easily removed when the tempering moisture increased. Short tempering time gave better separation of germ and endosperm, thus better yield of low fat grits. Desikachar (1986) also found that short prior moist conditioning of sorghum grain with 2-3 per cent moisture enabled removal of the bran by an abrasive machine similar to that used in rice milling.

Table 4.6 : Recovery of the fractions of treated pearl millet grains milled by rice polisher

Treatment	Scouring time (min)	Recovery (%)	
		Fraction-I	Fraction-II
Blanching (9 min)	3	73.2±1.14	26.0±1.45
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	3	88.2±0.94	11.3±0.94
Tempering at 14% moisture level 4h	3	71.6±0.60	27.6±0.59
Tempering at 16% moisture level 2h	3	73.1±0.73	26.2±0.85
4h	3	72.3±0.76	26.8±0.89
6h	3	70.5±0.50	28.8±0.41
Without treatment	3.5	81.2±0.57	18.1±0.68
CD (P/ 0.05)		0.92	0.38

Values are means ± SD of six determinations.

4.3.1.1 Fat and ash

Fat concentration in fraction I separated by barley pearler after selected treatments (Table 4.7) varied from 3.5 to 4.4 per cent. The treatments improved the level of fat as well as percentage of total fat of the grain present in fraction I; the fraction collected after different treatments contained more than half of the total fat of the grain. Fraction II from untreated grains contained about 50 per cent fat of the grain whereas in all the treated samples fat content was less than that. It implies that the treatments of the grain were not helpful in diverting a greater amount of fat in fraction II.

Similarly, fraction I contained more than 50 per cent of mineral matter present in the grain. Fraction II obtained after milling of the grains steeped in lime and blanched for 9 min contained lowest proportion of ash of all treated as well as untreated samples (Table 4.7). Lower amounts of ash in fraction II from lime steeped and blanched grains may be because of low fraction II recovery (Table 4.5). Steeping in $Ca(OH)_2$ might have dissolved and removed upper layer of grain which may be rich in mineral matter. Removal of organic matter by alkali retention of calcium and other minerals may account for increased concentration of mineral matter in fraction II.

Milling of untreated grains by rice polisher resulted in 50 per cent recovery of fat in fraction II (Table 4.8). All the treatments except acid steeping followed by blanching improved

Table 4.7 : Distribution of fat and ash (g/100 g) in the fractions of pearl millet milled by barley pearler

Treatment	Fraction-I		Fraction-II	
	Fat	Ash	Fat	Ash
Tempering at 16% moisture level 4h	4.20±0.07 (60.3)	1.05±0.05 (54.8)	17.6±0.08 (39.7)	5.51±0.08 (45.2)
Blanching (6 min)	4.11±0.06 (58.8)	0.97±0.03 (52.2)	16.7±0.10 (41.2)	5.15±0.07 (47.8)
Blanching (9 min)	4.06±0.05 (57.3)	0.95±0.03 (51.3)	16.4±0.08 (42.7)	4.90±0.05 (48.7)
Acid (0.2N. HCl) steeping for 6 h and blanching (9 min)	3.89±0.06 (56.8)	0.76±0.07 (51.5)	17.7±0.09 (43.2)	4.56±0.11 (48.5)
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	4.36±0.05 (68.0)	1.34±0.06 (68.0)	19.8±0.08 (32.0)	5.80±0.10 (32.0)
Without treatment	3.50±0.06 (49.1)	1.01±0.03 (54.4)	17.1±0.06 (50.9)	4.71±0.06 (45.6)
Whole pearl millet	6.05±0.08	1.64±0.05		
CD (P/ 0.05)	0.08	0.05	0.09	0.10

Values are means ± SD of five determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

Table 4.8 : Distribution of fat and ash (g/100 g) in the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I		Fraction-II	
	Fat	Ash	Fat	Ash
Blanching (9 min)	3.52±0.05 (42.5)	1.01±0.04 (45.4)	13.4±0.28 (57.5)	3.40±0.06 (54.6)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	4.13±0.09 (60.4)	0.62±0.07 (51.4)	21.1±1.54 (39.6)	4.60±0.10 (48.6)
Tempering at 14% moisture level 4h	3.44±0.05 (39.7)	0.99±0.02 (43.3)	13.6±0.08 (60.3)	3.38±0.08 (56.7)
Tempering at 16% moisture level, 2h	3.35±0.05 (40.7)	1.03±0.07 (45.7)	13.6±0.11 (59.3)	3.39±0.06 (54.3)
4h	3.31±0.05 (39.1)	1.01±0.09 (44.8)	13.9±0.26 (60.9)	3.38±0.05 (55.2)
6h	3.23±0.07 (36.8)	0.96±0.04 (40.9)	13.6±0.08 (63.2)	3.32±0.13 (59.1)
Without treatment	3.55±0.06 (49.6)	0.98±0.05 (48.6)	16.3±0.10 (50.4)	4.67±0.09 (51.4)
Whole pearl millet	6.05±0.08	1.64±0.05		
CD (P/ 0.05)	0.09	0.06	0.27	0.07

Values are means ± SD of five determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

the fat content of fraction II as compared to untreated sample. Acid treated fraction II had a relatively low proportion of total fat of the grain but the concentration of fat in this fraction was highest. Lowest recovery (Table 4.6) containing highest concentration of fat is one of the desirable qualities of the milling of the treated samples. Among the treatments, acid steeping followed by blanching and milling of dried sample in rice polisher for 3 min gave the highest recovery of fat in fraction II. Concentration of ash in fraction II milled by both rice polisher and barley pearler was relatively greater in fraction II than fraction I. Since fraction II contains a major part of bran which is rich in mineral matter the concentration of ash in fraction II is attributable to the bran part of grain.

Of the two machines barley pearler is capable of abrasing upper layer of grain and possibly detaching germ resulting in higher concentration of fat in fraction II. Rice polisher on the other hand gives less recovery of fraction I but fraction II contained a greater proportion of total fat. Fraction II obtained after alkali treatment contained highest proportion of fat in samples milled by barley pearler.

An increase in moisture content of grain has been reported to increase the amount of germ recovered and consequently increased the amount of fat separated in that fraction (Abdelrahman et al., 1983). The fat content of germ varied from 15.8 to 50.7 per cent

of total fat, at different tempering moisture levels and periods. DeWit and Schweigart (1970), also reported that milled grains contained 4.4 per cent fat as compared to 5.7 per cent fat of whole bajra.

Relatively higher ash content of fraction II may be attributed to mineral rich bran and aleurone layer of the grain being separated in fraction II. Adrian et al. (1975) reported that protein rich fraction of pearl millet obtained by SEPIAL milling process contained 4.11 per cent ash. Reichert and Youngs (1977) found that millet dehulled with laboratory barley pearler and village scale abrasive and attretion type mills contained 31-51 per cent less ash than whole millets. About 51, 46 and 45 per cent reduction in ash content of parl millet milled by traditional milling, barley pearler and tangential abrasive dehulling device, respectively has also been reported (ICRISAT, 1986).

4.3.1.2 Crude protein, true protein and non protein nitrogen

Whole pearl millet grain contained 10.2 per cent true protein and a very small amount of nonprotein nitrogen. Milling of untreated as well as treated grains by barley pearler produced fractions I and II which contained 8.6 to .9.25 and 17.4 and 19.4 per cent crude protein, respectively (Table 4.9). Most of the protein was present in the form of true protein in both fractions. The only difference was in the concentration of protein which was much higher in fraction II than fraction I. Steeping in calcium hydroxide

Table 4.9 : Distribution of crude protein, true protein (g/100 g) and non-protein nitrogen (mg/100 g) in fractions of pearl millet milled by barley pearler

Treatment	Fraction I			Fraction II		
	Crude protein	True protein	Non-protein nitrogen	Crude protein	True protein	Non-protein nitrogen
Tempering at 16% moisture level 4h	9.16±0.08 (75.8)	8.96±0.09 (76.0)	32.0±1.60 (73.0)	18.6±0.06 (24.2)	18.1±0.07 (24.0)	75.0±2.40 (27.0)
Blanching (6 min)	8.92±0.06 (74.3)	8.73±0.06 (74.2)	30.6±1.40 (72.2)	17.9±0.05 (25.7)	17.5±0.08 (25.8)	67.9±0.80 (27.8)
Blanching (9 min)	8.78±0.08 (72.6)	8.60±0.08 (72.6)	29.3±2.10 (70.5)	18.0±0.06 (27.4)	17.6±0.08 (74.4)	66.6±0.90 (29.5)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	8.61±0.06 (73.5)	8.44±0.08 (73.6)	25.9±2.50 (69.1)	18.6±0.06 (26.5)	18.2±0.06 (26.4)	69.3±0.60 (30.9)
Alkal. [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	9.25±0.07 (82.2)	9.05±0.07 (82.2)	32.4±0.82 (81.4)	19.4±0.08 (17.8)	18.9±0.10 (17.8)	71.4±1.60 (18.6)
Without treatment	9.04±0.11 (71.8)	8.83±0.08 (71.1)	33.6±1.10 (70.8)	17.4±0.08 (28.2)	17.0±0.09 (28.9)	65.7±1.40 (29.2)
Whole pearl millet	10.4±0.12	10.2±0.10	39.0±2.70			
CD (P / 0.05)	0.10	0.11	2.01	0.06	0.12	1.64

Values are means ± SD of five determinations .
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

for 6 h followed by blanching for 9 min produced fraction I containing significantly higher protein content than fraction I from untreated grains. Concentration of crude protein in fraction I obtained after other different treatments was significantly less than control. Fraction II from all the treated and untreated grains contained almost double the amount of protein found in fraction I. Fraction II after different treatments contained higher protein content than the fraction from untreated grains. Fraction II from alkali steeped and blanched grain had highest concentration of protein.

Milling of untreated sample by rice polisher produced fractions I and II containing 8.96 and 17.1 per cent crude protein, respectively (Table 4.10). Most of the protein in both the fractions was in the form of true protein. Fraction II contained relatively higher concentration of protein than fraction I. An increase in moisture level for tempering the grains didn't influence the concentration of crude protein in both the fractions. An increase in tempering period, howver, lowered the concentration of protein in fraction I, and increased the concentration in fraction II. Blanching for 9 min and steeping in acid followed by blanching for 9 min also raised the level of crude protein in fraction I as compared to concentration of protein in this fraction of untreated grains. Fraction II from acid steeped and blanched grains contained relatively higher concentration of protein than the fraction from other treated samples. The concentration of protein in fraction II of all the treated grains was not, however, higher than that

Table 4.10 Distribution of crude protein, true protein (g/100 g) and non-protein nitrogen (mg/100 g) in the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I			Fraction-II		
	Crude protein	True protein	Non-protein nitrogen	Crude protein	True protein	Non-protein nitrogen
Blanching (9 min)	9.02±0.06 (64.8)	8.81±0.07 (64.7)	33.0±1.20 (67.2)	13.8±0.06 (35.2)	13.5±0.07 (35.3)	45.3±2.40 (32.8)
Acid (0.2N HCL) steeping for 6 h and blanching (9 min)	9.24±0.07 (81.0)	9.06±0.08 (80.9)	28.6±2.30 (81.4)	16.9±0.18 (19.0)	16.6±0.14 (19.1)	50.9±1.30 (18.6)
Tempering at 14% moisture level 4h	9.18±0.06 (63.4)	8.95±0.08 (63.3)	37.0±2.46 (66.2)	13.8±0.09 (36.6)	13.5±0.08 (36.7)	49.2±1.20 (33.8)
Tempering at 16% moisture level 2h	9.30±0.08 (65.5)	9.07±0.07 (65.8)	36.2±1.00 (67.8)	13.6±0.12 (34.5)	13.3±0.10 (34.2)	47.9±1.02 (32.2)
4h	9.20±0.07 (62.2)	8.97±0.05 (64.0)	36.6±0.90 (66.4)	13.9±0.14 (37.8)	13.6±0.12 (36.0)	50.4±1.10 (33.6)
6h	9.08±0.05 (61.9)	8.86±0.08 (61.9)	35.3±0.80 (65.2)	13.7±0.08 (38.1)	13.4±0.09 (38.1)	46.2±2.07 (34.8)
Without treatment	8.96±0.05 (70.2)	8.75±0.06 (70.0)	33.9±1.12 (68.8)	17.1±0.16 (29.8)	16.9±0.12 (30.0)	69.2±1.97 (31.2)
Whole pearl millet	10.4±0.12	10.2±0.10	39.0±2.70			
CD (P/ 0.05)	0.09	0.10	1.60	0.12	0.09	2.05

Values are means ± SD of five determinations
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

in fraction II of untreated grains. Milling of treated as well as untreated pearl millet grains by both the mills showed that fraction I contained higher proportion of protein than fraction II. Rice polisher seems to possess an advantage of milling the grains and providing relatively less concentration of protein in fraction II. Tempering and blanching seemed to be most effective in restraining the concentration and proportion of protein in fraction II. Fraction II obtained from the milling of treated samples by barley pearler on the other hand contained higher concentration of protein than the fraction from untreated sample (Table 4.9).

Since the bran and germ are known to contain higher concentration of protein (Abdelrahman, 1984) higher concentration of protein in fraction II, containing bran and germ is expected. Higher recovery of fraction I by barley pearler and lower concenration of protein in this fraction in comparison with the rice polisher implies that fraction II obtained by milling of pearl millet grains with rice polisher had lower protein concentration. Contamination of bran and germ with grits has, perhaps, diluted the protein concentration in fraction II of rice polisher.

Reichert and Youngs (1977) milled pearl millet by barley pearler and abrasive and attrition type mills and reported that endosperm contained 9 to 18 per cent less protein at 75 per cent extraction rate than whole grain. Traditional milled grains lost about 5 to 8 per cent protein. A reduction of 27, 19 and 24

per cent in protein content of pearl millet after milling by traditional method, barley pearler and tangential abrasive dehulling device respectively, has also been reported (ICRISAT, 1986).

4.3.1.3 Available carbohydrates

Available carbohydrates of whole grains of pearl millet comprised of mainly starch and about 2 per cent total soluble sugars. Soluble sugars were mainly in the form of non-reducing sugars. Milling by barley pearler could remove only a minor proportion of total starch of the grain in fraction II. Fraction I on the other hand contained most of the starch present in whole grain (Table 4.11). Any of the treatments prior to milling did not improve the concentration of starch in fraction I where as 9min blanching, tempering at 16 per cent moisture level for 4 h and alkali steeping lowered the starch content of fraction II. Concentration of total soluble sugars and non-reducing sugars was by and large same in both the fractions but since fraction I formed a major portion of the grain more than 80 per cent of total soluble sugars remained in this fraction. Non-reducing sugars on the other hand were in greater concentration in fraction II than in fraction I.

Milling by rice polisher also separated the grain into two fractions of which fraction I contained most of its starch, soluble sugars, reducing sugars and non-reducing sugars. Concentration of the sugars in both the fractions was almost same. The treatments including blanching and tempering at both 14 and 16 per

Table 4.11 : Distribution of total soluble sugar (TSS), reducing sugar (RS), non-reducing sugar (NRS) and starch(g/100 g) in the fractions of pearl millet milled by barley pearler

Treatment	Fraction-I				Fraction-II			
	TSS	RS	NRS	Starch	TSS	RS	NRS	Starch
Tempering at 16% moisture level 4h	1.81±0.03 (85.5)	0.33±0.02 (80.0)	1.48±0.02 (86.5)	76.5±0.50 (99.4)	1.96±0.03 (14.5)	0.49±0.02 (20.0)	1.47±0.02 (13.5)	3.10±0.13 (0.6)
Blanching (6 min)	1.80±0.03 (84.1)	0.32±0.02 (79.4)	1.48±0.02 (86.0)	77.9±1.22 (99.3)	1.92±0.03 (15.9)	0.47±0.01 (20.6)	1.48±0.04 (14.0)	3.45±1.04 (0.7)
Blanching (9 min)	1.78±0.04 (83.3)	0.31±0.02 (76.5)	1.47±0.02 (84.8)	78.9±1.19 (99.3)	1.91±0.02 (16.7)	0.46±0.02 (23.5)	1.44±0.03 (15.2)	3.14±1.10 (0.7)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	1.58±0.04 (83.3)	0.27±0.03 (76.7)	1.32±0.03 (87.6)	76.5±1.43 (99.2)	1.90±0.04 (16.7)	0.51±0.01 (23.3)	1.39±0.03 (12.4)	3.54±0.08 (0.8)
Alkali [0.5% $Ca(OH)_2$]: steeping for 6 h and blanching (9 min)	1.73±0.02 (89.1)	0.30±0.03 (87.1)	1.44±0.01 (91.0)	72.4±1.38 (99.5)	1.91±0.03 (10.9)	0.43±0.03 (12.9)	1.48±0.02 (9.0)	3.06±0.12 (0.5)
Without treatment	1.80±0.03 (81.6)	0.33±0.02 (75.0)	1.47±0.03 (82.2)	79.3±1.46 (99.1)	1.94±0.04 (18.4)	0.51±0.04 (25.0)	1.43±0.04 (17.8)	3.56±0.05 (0.9)
Whole pearl millet	1.84±0.03	0.35±0.03	1.49±0.04	65.5±2.13				
CD (P/ 0.05)	0.04	0.03	0.04	1.97	0.04	0.02	0.03	1.10

Values are means ± SD of four determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

per cent moisture level increased the starch content of fraction I; total sugars were not affected. These treatments had almost the same effect on concentration of total soluble sugar and starch in fraction II. An increase at 16 per cent moisture level in tempering time from 2 to 6 h didn't make any significant difference in the level of starch and sugars in both the fractions. Acid steeping combined with blanching produced a different result. Concentration of starch and non-reducing sugars decreased where as total soluble sugars and reducing sugars showed an increase in fraction II. Level of starch and sugars in fraction I was lowered significantly by this treatment. (Table 4.12)

Removal of complex carbohydrates, mineral matter and fat in fraction II consisting mainly of bran and germ has perhaps resulted in an increase in the concentration of starch in fraction I as endosperm, represented in fraction I, has been well known to be a source of starch in pearl millet and other cereals.

Dehulled grains of pearl millet obtained after milling by traditional method, barley pearler and tangential abrasive dehulling device (TADD) contained significantly less total soluble sugar than whole grains, their starch content was increased from 76.7 to 81.8, 82.4 and 80.7 per cent, respectively after dehulling (ICRISAT, 1986). Amarjeet et al. (1990) reported that debranning of wheat resulted in reduction in the level of total and non-reducing sugar. Starch and reducings sugars on the other hand increased after debranning.

Table 4.12 : Distribution of total soluble sugar (TSS), reducing sugar (RS), non-reducing sugar (NRS) and starch(g/100g) in the fractions of pearl millet by rice polisher

Treatment	Fraction-I				Fraction-II			
	TSS	RS	NRS	Starch	TSS	RS	NRS	Starch
Blanching (9 min)	1.74±0.03 (70.5)	0.30±0.03 (70.0)	1.44±0.05 (70.9)	82.0±0.80 (97.2)	2.03±0.08 (29.5)	0.37±0.04 (30.0)	1.66±0.07 (29.1)	6.56±1.24 (2.8)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	1.71±0.06 (88.8)	0.20±0.02 (85.3)	1.40±0.10 (89.1)	72.7±1.84 (99.6)	1.67±1.02 (11.2)	0.39±0.07 (14.7)	1.28±0.03 (10.9)	2.33±0.14 (0.4)
Tempering at 14% moisture level 4h	1.77±0.04 (70.2)	0.35±0.02 (71.0)	1.42±0.03 (69.6)	81.0±1.83 (96.3)	1.98±0.28 (29.8)	0.36±0.08 (29.0)	1.62±0.04 (30.4)	8.18±1.09 (3.70)
Tempering at 16% moisture level 2h	1.78±0.08 (71.8)	0.37±0.02 (78.1)	1.41±0.03 (71.0)	80.4±1.75 (96.5)	1.94±0.24 (28.2)	0.34±0.03 (21.9)	1.60±0.04 (29.0)	8.10±1.10 (3.5)
4h	1.75±0.05 (70.2)	0.36±0.03 (75.6)	1.39±0.05 (69.2)	80.7±1.21 (96.4)	2.01±0.10 (29.8)	0.31±0.03 (24.4)	1.70±0.05 (30.8)	8.06±0.06 (3.60)
6h	1.75±0.06 (68.2)	0.34±0.03 (70.3)	1.40±0.04 (67.7)	81.4±1.81 (96.1)	2.00±0.14 (31.8)	0.35±0.04 (29.7)	1.65±0.04 (32.3)	8.11±0.07 (3.9)
Without treatment	1.80±0.04 (80.2)	0.32±0.04 (79.9)	1.48±0.04 (80.5)	77.7±2.40 (98.8)	1.99±0.05 (19.8)	0.36±0.4 (20.1)	1.63±0.02 (19.5)	4.02±1.08 (1.20)
Whole pearl millet	1.84±0.03	0.35±0.03	1.49±0.04	65.5±2.13				
CD (P/ 0.05)	0.05	0.03	0.04	2.86	0.06	0.02	0.04	1.12

Values are means ± SD of four determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

4.3.2 Protein and starch digestibility (in vitro)

In vitro protein and starch digestibility of whole pearl millet grain showed that pearl millet is a poorly digestible grain. Protein and starch retained in fraction 1 after milling of untreated grains both by barley pearler and rice polisher possessed better digestibility than those in fraction II. Milling, therefore, removes a part of protein and carbohydrate which is poorly digestible. Blanching as well as acid steeping combined with blanching increased whereas 6 min blanching and tempering at 16 per cent moisture level for 4 h did not change in vitro digestibility of protein in fraction I milled by barley pearler (Table 4.13). On the other hand tempering and alkali steeping significantly decreased; 9 min blanching and acid steeping - blanching increased and 6 min blanching didn't change significantly the digestibility of starch present in fraction I. Acid steeping-blanching and 9 min blanching increased and tempering at 16 per cent moisture level for 4 h did not change protein as well as starch digestibility in fraction II milled by barley pearler. Alkali steeping-blanching decreased protein digestibility but increased starch digestibility of fraction II significantly.

All the treatments including 9 min blanching, 0.2 N HCl steeping (6 h) and 9 min blanching, tempering at 14 per cent moisture level for 4 h and tempering at 16 per cent moisture level for 2,4 and 6 h improved the digestibility of both starch and protein in fraction I milled by rice polisher. In fraction II, starch digestibility was increased only by acid steeping and protein digestibility by blanching. Other treatments either lowered or did not change the digestibilities (Table 4.14).

Table 4.13 : In vitro protein (%) and starch (mg maltose released/g) digestibility in the fractions of pearl millet milled by barley pearler

Treatment	Fraction-I		Fraction-II	
	Protein digestibility	Starch digestibility	Protein digestibility	Starch digestibility
Tempering at 16% moisture level 4h	75.4±1.21	25.5±0.58	37.4±0.6	3.04±1.04
Blanching (6 min)	78.6±1.04	33.1±1.75	38.8±0.32	4.28±1.29
Blanching (9 min)	80.0±1.10	37.8±0.56	42.2±0.90	3.46±4.85
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	82.1±1.10	41.1±0.72	44.1±0.88	5.90±1.05
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	68.5±0.96	23.2±2.30	36.3±0.67	6.12±3.45
Without treatment	75.5±0.60	30.5±3.50	38.0±0.80	3.98±1.07
Whole pearl millet	62.2±0.38	18.0±2.90		
CD (P/ 0.05)	3.27	4.45	0.96	1.54

Values are means ± SD of four determinations.

Table 4.14 : In vitro protein (%) and starch (mg maltose released/g) digestibility in the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I		Fraction-II	
	Protein digestibility	Starch digestibility	Protein digestibility	Starch digestibility
Blanching (9 min)	81.2±1.10	37.9±2.28	39.8±1.55	4.60±1.80
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	82.1±0.67	39.5±3.46	37.2±0.42	8.10±1.50
Tempering at 14% moisture level 4 h	79.7±1.58	31.8±1.43	34.3±0.37	3.86±0.63
Tempering at 16% moisture level 2h	76.0±1.10	32.0±3.54	35.2±0.48	4.21±1.43
4h	79.6±0.60	32.5±0.49	33.4±0.65	3.56±0.54
6h	79.2±0.48	33.2±4.44	32.0±0.62	3.06±0.68
Without treatment	73.6±0.80	29.6±4.58	37.6±0.72	4.45±1.01
Whole pearl millet	62.2±0.38	18.0±2.90		
CD (P / 0.05)	2.68	5.23	0.85	1.98

Values are means ± SD of four determinations.

Chauhan et al. (1986) reported that protein digestibility of pearl millet varieties ranged from 58 to 68 per cent. Pawar and Parlikar (1990) observed a significant increase in in vitro protein digestibility IVPD from 66.3 to 82.8 per cent after dehulling and soaking of pearl millet. Dehulling of finger millet has been reported to increase IVPD (Ramachandra et al., 1977).

Reduction in polyphenols and phytic acid content of fraction I by milling might result in the improved protein and starch digestibility of this fraction. Yoon et al. (1983) also reported similar results and found an increase in starch digestibility which was attributed to the reduction of phytic acid. The addition of tannic acid to dehulled pearl millet flour lowered IVPD but not to the same extent as in whole seed samples. This difference could be due to the dehulling loss of other polyphenolic compounds present in the seed coat (Ramchandra et al. (1977). Addition of tannic acid and phytic acid has been reported to reduce the starch digetibility by 13 and 60 per cent after 5 h, respectively (Thompson et al., 1984).

4.3.3 Polyphenols and phytic acid

Whole pearl millet grain contained 285 and 685 mg/100 g of polyphenols and phytic acid, respectively. Milling by barley pearler separated these two antinutrients in fraction I and fraction II. Fraction II contained about 69 per cent of polyphenols and 40 per cent of phytic acid (Table 4.15). Concentration of these antinutrients in fraction II was much higher than in fraction I.

Table 4.15 : Distribution of polyphenols and phytic acid (mg/100 g) in the fractions of pearl millet milled by barley pearler

Treatment	Fraction-I		Fraction-II	
	Polyphenol	Phytic acid	Polyphenol	Phytic acid
Tempering at 16% moisture level 4h	118±1.77 (37.0)	452±4.20 (57.1)	1281±6.53 (63.0)	2170±5.84 (42.9)
Blanching (6 min)	75.2±1.72 (27.4)	441±9.46 (56.5)	1174±5.02 (72.6)	1961±5.85 (43.5)
Blanching (9 min)	71.5±1.36 (25.4)	419±7.50 (53.6)	1140±6.42 (74.6)	1976±6.40 (46.4)
Acid (0.2N HCl) steeping for 6 h and blanching (9min)	51.1±6.09 (27.0)	343±4.60 (52.0)	720±9.71 (73.0)	1898±7.80 (48.0)
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	86.9±2.43 (39.4)	514±6.80 (70.8)	1154±5.10 (60.6)	2043±8.96 (29.2)
Without treatment	101±6.85 (29.4)	428±9.35 (51.6)	1148±8.87 (70.6)	1904±6.45 (48.4)
Whole pearl millet	285±6.35	685±11.2		
CD (P/ 0.05)	8.56	18.2	16.9	30.8

Values are means ± SD of six determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

Milling, therefore, is an effective method of getting rid of the persistent and obnoxious antinutritional factors from the grains. Tempering and alkali steeping were not that effective in removing polyphenols from the grains through milling as blanching and acid steeping. Acid steeping lowered phytic acid content of fraction I to a greater extent. Fraction I obtained after tempering at 16 per cent moisture level for 4 h and alkali steeping with blanching had higher levels of phytic acid than the fraction from untreated grains (Table 4.15).

Fraction II obtained after milling with rice polisher contained 65 per cent polyphenols and 51 per cent phytic acid present in the untreated grains. All the treatments were instrumental in reducing the polyphenols in fraction I milled by rice polisher; fraction I of acid steeped grains had lowest concentration. Of all the treatments acid steeping could reduce phytic acid content of fraction I significantly (Table 4.16). It was reported that Phytic acid primarily occurs in the outer seed coat (bran) and and germ of plant seeds (Oberleas, 1973). Wang et al . (1959) examined the distribution of phytic acid in seven cultivars of sorghum and found maximum phytic acid in germ ranging from 1920 to 6780 mg/100 g followed by 670-1920 mg/100 g in bran. Grits contained only 70-640 mg/100 g as compared to 710 mg/100 g in whole grains. Endosperm of wheat and rice kernels is almost devoid of phytic acid, because it is concentrated in the germ and aleurone layers (pericarp) of the kernel cells (O'Dell et al., 1972). Corn endosperm

Table 4.16 : Distribution of polyphenols and phytic acid (mg/100 g) in the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I		Fraction-II	
	Polyphenol	Phytic acid	Polyphenol	Phytic acid
Blanching (9 min)	86.3±2.35 (25.9)	431±4.42 (47.2)	695±8.02 (74.1)	1338±4.68 (52.8)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	63.8±2.14 (20.4)	343±2.54 (55.2)	1041±9.90 (79.6)	2170±18.4 (44.8)
Tempering at 14% moisture level 4 h	103±3.29 (26.7)	422±4.40 (44.3)	742±6.26 (73.3)	1381±9.88 (55.7)
Tempering at 16% moisture level 2h	101±2.38 (26.8)	436±8.26 (46.4)	772±7.56 (73.2)	1404±16.5 (53.6)
4h	110±4.08 (25.7)	433±9.29 (45.5)	780±6.29 (74.3)	1386±6.76 (54.5)
6h	105±4.21 (25.8)	417±9.87 (43.1)	737±7.68 (74.2)	1348±9.92 (56.9)
Without treatment	116±5.76 (33.7)	413±8.90 (49.0)	1332±10.0 (66.3)	1933±8.93 (51.0)
Whole pearl mill	285±6.35	685±11.2		
CD (P/ 0.05)	8.14	23.2	17.1	28.2

Values are means ± SD of six determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

also had small amounts of (3.2 per cent) phytic acid but the major portion of phytic acid was in aleurone layers. In rice too, of the total phytic acid, 84.0 to 88.0 per cent was reported to be in bran (Resurreccion et al., 1979). Polyphenolic content of pearl millet decreases by the traditional practice of soaking the grains in sour milk or in aqueous extract of tamarind (Reichert, 1979). According to Panwal and Panwar (1989) HCl was most effective bleaching agent which removed pigements in the pearl millet to the extent of 74.3 per cent during 24 h soaking time. Dehulling of sorghum by abrasion mill has been reported to remove about 74 per cent of the tannin of the grains (Chibbar et al., 1978).

4.3.4 Minerals

A perusal of data in Tables 4.17 and 4.18 revealed that fraction II obtained after milling the untreated grains both by barley pearler and rice polisher were richer in calcium as well as in phosphorus than fraction I. This implied that upper layer of grain and germ are rich sources of calcium and phosphorus. Fraction I contained more calcium when grains before milling were tempered at 14 or 16 per cent moisture level; retention seemed to be inversely proportional to tempering time (Tables 4.17 to 4.18). Blanching alone didn't significantly change the calcium concentration in fraction I milled by barley pearler whereas concentration in this fraction was significantly reduced in rice polisher milling. Calcium concentration in fraction I increased several folds when alkali steeped

Table 4.17 : Distribution of calcium and phosphorus (mg/100 g) in the fractions of pearl millet milled by barley pearler

Treatment	Fraction-I				Fraction-II			
	Total calcium	Extract able calcium	Total phosphorus	Extract-able phosphorus	Total calcium	Extract-able calcium	Total phosphorus	Extract-able phosphorus
Tempering at 16% moisture level 4h	37.6±1.18 (60.0)	17.3±0.88 (83.9)	185±3.57 (55.2)	77.9±2.01 (81.8)	160±1.25 (40.0)	21.2±1.12 (16.1)	957±6.82 (44.8)	111±2.02 (18.2)
Blanching (6 min)	32.8±1.05 (53.4)	18.4±1.02 (85.9)	174±2.87 (54.4)	79.7±1.01 (82.7)	165±1.01 (46.6)	17.4±1.79 (14.1)	842±5.26 (45.6)	96.3±2.94 (17.3)
Blanching (9 min)	30.8±0.75 (50.0)	17.9±0.85 (83.6)	163.3±4.84 (51.0)	78.0±1.78 (81.2)	167±1.08 (50.0)	19.1±1.09 (16.4)	847±3.16 (49.0)	97.8±2.88 (18.8)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	23.6±2.10 (49.9)	13.5±1.23 (79.9)	130±6.20 (50.5)	72.0±2.50 (82.5)	142±1.76 (50.1)	20.4±1.23 (20.1)	763±8.89 (49.5)	91.6±1.32 (17.5)
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	110±4.26 (78.7)	48.7±2.15 (84.9)	204±6.30 (69.5)	82.5±1.50 (89.4)	288±7.24 (21.3)	83.3±2.49 (15.1)	863±6.15 (30.5)	94.7±7.04 (10.6)
Without treatment	31.3±0.97 (46.8)	16.9±0.76 (78.3)	173±5.20 (49.4)	80.4±1.05 (80.5)	169±1.45 (53.2)	22.3±0.86 (21.7)	841±4.38 (50.6)	92.6±4.35 (19.5)
Whole pearl millet	54.8±3.43	17.4±1.46	290±5.38	81.4±2.20				
CD (P / 0.05)	1.60	1.35	14.8	8.34	1.76	2.45	25.8	11.4

Values are means ± SD of four determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

Table 4.18 : Distribution of calcium and phosphorus (mg/100 g) in the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I				Fraction-II			
	Total calcium	Extract-able calcium	Total phos-phorus	Extract-able phosphorus	Total calcium	Extract-able calcium	Total phos-phorus	Extract-able phosphorus
Blanching (9min)	29.8±0.84 (42.0)	17.0±0.82 (68.5)	160±1.23 (43.4)	85.4±1.45 (75.5)	114±1.20 (58.0)	21.7±0.78 (31.5)	587±4.33 (56.6)	78.1±2.02 (24.5)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	23.0±2.60 (50.2)	12.5±1.43 (74.3)	134±2.20 (52.6)	72.0±2.38 (80.4)	178±2.15 (49.8)	32.8±0.38 (25.7)	955±2.86 (47.4)	140±3.18 (19.6)
Tempering at 14% moisture level 4h	33.0±0.76 (44.0)	18.2±0.84 (70.7)	178±2.45 (42.6)	86.2±1.02 (74.6)	109±0.76 (56.0)	19.6±0.96 (29.3)	601±2.96 (57.4)	76.4±1.45 (25.4)
Tempering at 16% moisture level 2h	34.6±1.50 (47.0)	17.4±0.73 (69.4)	176±3.20 (44.6)	84.4±0.78 (75.0)	107±0.95 (53.0)	21.4±0.48 (30.6)	608±6.14 (55.4)	78.3±1.26 (25.0)
4h	33.2±0.85 (44.5)	17.8±0.67 (69.6)	170±1.10 (43.0)	85.1±0.85 (75.4)	112±1.41 (55.5)	21.0±0.58 (30.4)	602±10.6 (57.0)	75.2±1.40 (24.6)
6h	32.5±0.94 (42.9)	18.5±0.45 (70.4)	166±3.2 (41.2)	87.4±1.65 (76.0)	106±0.88 (57.1)	19.1±0.52 (29.6)	582±8.10 (58.8)	67.6±2.40 (24.0)
Without treatment	31.2±1.04 (46.9)	16.6±0.80 (73.9)	169±4.23 (47.8)	78.4±1.30 (77.7)	159±1.95 (53.1)	26.5±1.32 (26.1)	833±9.45 (52.2)	101±2.82 (22.3)
Whole pearl millet	54.8±3.43	17.4±1.46	290±5.38	81.4±2.20				
CD (P / 0.05)	1.02	0.70	12.8	8.88	1.08	0.85	23.8	12.0

Values are means ± SD of three determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

grains were milled by barley pearler; increase in concentration of fraction II was relatively low. Calcium from steeping medium seemed to have percolated deeper into the grain resulting in its higher concentration in fraction I.

Blanching and alkali steeping led to increased concentration of HCl extractable calcium in fraction I milled by barley pearler; other treatments lowered its amount. Tempering at 14 and 16 per cent moisture level resulted in increasing the amount of HCl extractable Ca in fraction I; milled by rice polisher; higher the temperi-ng period greater was the increase. Blanching alone did not change the amount of extractable calcium where as acid steeping with blanching reduced it to a significant extent (Table 4.18). Grain treatments didn't change HCl-extractable phosphorus in fraction I milled by barley pearler whereas acid steeping-blanching, alkali steeping-blanching decreased and increased total phosphorus significantly, respectively. Acid steeping-blanching was the only treatment which altered the concentration of total as well as HCl-extractable phosphorus in fraction I milled by rice polisher as a result fraction I contained significantly lower total and extractable phosphorus.

Milling of pearl millet grains by barley pearler resulted in taking away more than 50 per cent of total iron of the grain to fraction II (Table 4.19). Concentration of iron in fraction II increased when grains after alkali steeping-blanching were milled by barley pearler. No other treatment caused an increase in the

Table 4.19 : Distribution of iron and zinc (mg/100 g) in the fractions of pearl millet milled by barley parler

Treatment	Fraction-I				Fraction-II			
	Total iron	Extract-able iron	Total zinc	Extra-able zinc	Total iron	Extract-able iron	Total zinc	Extract-able zinc
Tempering at 16% moisture level 4h	7.33±0.16 (52.2)	2.10±0.03 (78.4)	2.41±0.09 (50.6)	1.30±0.03 (74.2)	42.9±1.28 (47.8)	3.70±0.04 (21.6)	15.1±0.16 (49.4)	2.89±0.08 (25.8)
Blanching (6 min)	6.89±0.12 (49.7)	2.15±0.04 (77.6)	2.28±0.06 (49.2)	1.34±0.06 (75.5)	41.6±4.95 (50.3)	3.59±0.09 (22.4)	13.6±0.09 (50.8)	2.52±0.06 (24.5)
Blanching (9 min)	6.60±0.10 (47.2)	2.21±0.04 (77.9)	2.23±0.05 (47.8)	1.39±0.04 (76.2)	40.1±2.14 (52.8)	3.42±0.10 (22.1)	13.2±0.10 (52.2)	2.33±0.07 (23.8)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	5.20±0.18 (48.4)	1.84±0.08 (76.2)	1.97±0.07 (45.4)	1.20±0.06 (71.4)	32.9±3.34 (51.6)	3.38±0.07 (23.8)	14.4±0.14 (54.6)	2.92±0.12 (28.6)
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	6.92±0.10 (53.4)	2.00±0.07 (79.2)	2.80±0.08 (65.0)	1.41±0.04 (84.7)	58.2±4.18 (46.6)	5.09±0.12 (20.8)	14.6±0.09 (35.0)	2.44±0.06 (15.3)
Without treatment	6.64±0.54 (42.0)	2.04±0.05 (73.7)	2.31±0.04 (46.5)	1.35±0.05 (74.4)	43.6±1.46 (58.0)	3.50±0.08 (26.3)	12.6±0.08 (53.5)	2.21±0.05 (25.6)
Whole pearl millet	11.8±0.41	2.12±0.06	4.09±0.17	1.50±0.08				
CD (P/ 0.05)	0.15	0.11	0.10	0.06	1.48	0.15	0.09	0.11

Values are means ± SD of four determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

content of total iron in that fraction. Level of iron in fraction I on the other hand increased significantly when grains were tempered at 16 per cent moisture level for 4 h, blanched for 6 min alkali steeped - blanched & blanched for 9 min. / Acid steeping-blanching pertinently caused reduction in iron concentration in both fraction I and fraction II. Fraction I of untreated as well as treated sample possessed a greater proportion of HCl extractable iron than fraction II of corresponding treatments; not withstanding higher concentration of extractable iron of fraction II of these samples.

Total zinc and extractable zinc exhibited the same trend of distribution as that of total and extractable iron in the fractions of treated and untreated grains. Fraction I and fraction II of untreated grains milled by rice polisher contained equal proportion of total iron present in the whole grain. Concentration of the element, however, was much greater in fraction II than fraction I. Tempering at both levels of moisture didn't change the concentration of total iron in fraction I (Table 4.20) whereas acid steeping-blanching could lower it to a significant extent. As regards iron concentration in fraction II acid steeping blanching increased significantly whereas all other treatments reduced it. More than half of total extractable iron resided in fraction I of treated as well as untreated grains. Fraction I obtained after various treatments of grain and milled by rice polisher contained significantly less amount of zinc than that of untreated grains. Zinc concentration in fraction II for the treated samples except acid steeped- blanched grains was

Table 4.20 : Distribution of iron and zinc (mg/100 g) in the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I				Fraction-II			
	Total iron	Extract-able iron	Total zinc	Extract-able zinc	Total iron	Extract-able iron	Total zinc	Extract-able zinc
Blanching (9 min)	6.97±0.24 (44.9)	2.37±0.03 (63.5)	2.40±0.12 (45.7)	1.55±0.04 (73.7)	29.0±1.02 (55.1)	2.37±0.09 (36.5)	8.02±0.16 (54.3)	1.56±0.04 (26.3)
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	4.89±1.38 (48.6)	1.17±0.07 (76.6)	1.70±0.18 (47.2)	1.15±0.08 (72.1)	40.4±1.84 (51.4)	4.06±0.24 (23.4)	14.5±0.12 (52.8)	2.90±0.14 (27.9)
Tempering at 14% moisture level 4h	7.26±0.18 (43.2)	2.40±0.06 (62.5)	2.53±0.06 (44.6)	1.52±0.07 (72.2)	28.7±0.30 (56.8)	2.40±0.08 (37.5)	8.22±0.14 (55.4)	1.52±0.04 (27.8)
Tempering at 16% moisture level 2h	7.47±0.10 (44.5)	2.24±0.04 (61.9)	2.57±0.08 (46.1)	1.45±0.06 (70.4)	28.0±0.28 (55.5)	2.24±0.17 (38.1)	8.39±0.09 (53.9)	1.70±0.07 (29.6)
4h	7.36±0.08 (44.1)	2.28±0.03 (61.6)	2.49±0.07 (44.2)	1.49±0.06 (71.5)	28.4±0.35 (55.9)	2.28±0.04 (38.4)	8.49±0.08 (55.8)	1.60±0.09 (28.5)
6h	7.34±0.07 (42.4)	2.42±0.05 (62.9)	2.47±0.08 (42.8)	1.53±0.08 (71.9)	26.9±0.67 (57.6)	2.42±0.10 (37.1)	8.09±0.04 (57.2)	1.46±0.05 (28.1)
Without treatment	7.40±0.12 (50.5)	2.22±0.03 (78.0)	2.40±0.10 (47.6)	1.32±0.12 (71.7)	32.8±1.10 (49.5)	2.82±0.12 (22.0)	12.0±0.15 (52.4)	2.35±0.12 (28.3)
Whole pearl millet	11.8±0.41	2.12±0.06	4.09±0.17	1.50±0.08				
CD (P/ 0.05)	0.23	0.18	0.07	0.04	1.08	0.08	0.10	0.12

Values are means ± SD of four determinations.
Figures in parentheses indicate percentage of the sum of absolute amount in both the fractions.

also significantly less than that in fraction II of untreated sample Acid steeping-blanching caused a significant increase in zinc concentration of fraction II. Fraction I of treated as well as untreated grains contained a major chunk of HCl-extractable zinc.

This is clear from the results (Tables 4.17 to 4.20) that calcium phosphorus, iron and zinc are concentrated in outer covering of pearl millet grain and milling results in their higher concentration in fraction II. Fraction I not only contained higher proportion of HCl-extractable Calcium, phosphorus, iron and zinc present in te grain but extractability of these minerals was also high as compared to that of whole pearl millet grain. This might have occurred because of significant reduction in polyphenols and phytic acid level of fraction I during milling whivch are known to interfere with availability of minerals.

Calcium, phosphorus and iron are significantly reduced by removal of the outer pericarp, though the highest concentration of phytate occurs in germ (Hulse et al., 1980). Varriano-Marston and Hoseney (1980) reported most of the phosphorus in the germ. High levels of iron were in the germ and covering layers. In general, the endosperm was low in minerals and iron. Kurien and Desikachar (1966) also found that milling of finger millet gave the husk fractions rich in calcium and phosphorus. According to Awadalla and Slump (1974) decorticated Egyptian millet contained only 10, 1.3 and 0.8 mg/100 g of Calcium, iron and zinc, respectively as compared to 40, 2.8 and 2.5 mg/100 g of calcium, iron

and zinc of whole pearl millet. Desikachar (1977) in a similar study reported that bran of pearl millet contained 1450 mg/100 g phosphorus. A reduction in phosphorus content of pearl millet grains from 3.16 to 1.76 mg/g was found after dehulling and soaking in 0.2N HCl.

4.3.5 Fatty acid composition

Fatty acid composition of whole pearl millet revealed that C1812 acid was the most dominating fatty acid, constituting about 45 per cent of total fatty acids (Table 4.21). Oleic (18:1) (C 1610) and palmitic were other major fatty acid constituents respresnting about 27 and 19 per cent of total fatty acids, respectively. Distribution of fatty acids in fraction I and fraction II was marginally changed when untreated pearl millet grain was milled by barley pearler. Though linoleic acid continued to be major fatty acid of both the fractions but it represented a greater percentage in fraction I than fraction II. Treatments of the grain brought about marginal changes in the fatty acid composition profile of the fraction. Most significant changes appeared to be of low level on fraction I and of high level in fraction II of linoleic acid, when seeds were milled, after acid steeping-blanching (Table 4.21).

Milling of acid steeping-blanching grains by rice polisher also brought about similar changes in linoleic content of fractions (Table 4.22). Rest of the changes in fatty acid composition by rice polisher did not seem noticeable. These results are supported

Table 4.21 : Fatty acid composition of the fractions of pearl millet milled by barley pearler

Treatment	Fraction-I							Fraction-II						
	16:0	16:1	18;0	18:1	18:2	18:3	Others	16:0	16:1	18:0	18:1	18:2	18:3	Others
Tempering at 16% moisture level 4h	18.4	0.34	4.80	26.4	45.8	3.18	1.08	10.0	0.31	10.3	32.1	44.4	2.08	2.09
Blanching (6 min)	17.6	0.26	4.40	29.0	39.5	2.03	1.21	19.4	0.28	6.30	26.6	39.7	5.65	2.07
Blanching (9 min)	17.4	0.28	4.70	27.7	16.1	2.48	1.34	19.7	0.28	6.00	27.6	38.8	5.85	1.77
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	19.8	0.13	5.90	27.2	41.0	4.70	1.27	19.5	0.33	4.45	27.1	44.9	3.01	0.71
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	19.2	0.37	4.16	26.1	46.4	3.15	0.62	20.0	0.30	5.89	27.4	42.8	2.68	0.93
Without treatment	17.9	0.31	4.20	25.8	47.6	3.03	1.12	19.5	0.10	6.29	26.8	41.8	3.85	1.66
Whole pearl millet	18.6	0.31	4.89	26.9	44.9	3.10	1.30							

Values are means of two replicates.

by the findings of Jelleum and Powell (1971) in which linoleic was major fatty acid 40-51.7%, followed by oleic (20.2-30.6%) and palmitic acid (17.7-25.0%) in lipids of pearl millet. Chaudhary (1981) also reported that the linoleic, oleic and palmitic acids were the principal acids in free lipids. Linoleic acid was the predominant unsaturated fatty acid which accounts for 45 per cent of the total fatty acids. Results obtained in Tables 4.21 and 4.22 showed that major fatty acids in pearl millet are not concentrated entirely covering layer but they are distributed evenly throughout the grain.

As Milling of pearl millet grain, treated as well as untreated, by barley pearler and rice polisher helps in recovering a major part of total fat of the grain in fraction II and fatty acid composition of oil in this fraction is similar to that in milled fractions of other cereals like corn germ the fraction II can, therefore, be utilised as a source of edible oil.

4.4 Storability

Fraction I representing endosperm and a prospective portion of milled grains usable for human nutrition, was stored at 25, 30 and 35°C for 15 and 30 days. Free fatty acid lipase activity, fat acidity, peroxide value and lipoxygenase activity in these fractions, obtained after milling of treated as well as untreated sample by both barley pearler and rice polisher were determined.

Table 4.22 : Fatty acid composition of the fractions of pearl millet milled by rice polisher

Treatment	Fraction-I							Fraction-II						
	16:0	16:1	18:0	18:1	18:2	18:3	Others	16:0	16:1	18:0	18:1	18:2	18:3	Others
Blanching (9 min)	18.0	0.30	4.60	27.0	47.2	2.20	0.70	19.8	0.29	4.86	26.4	41.4	5.88	1.37
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	19.5	0.21	6.02	27.6	40.0	4.80	1.87	19.4	0.36	4.65	27.2	44.8	2.91	0.68
Tempering at 14% moisture level 4h	19.0	0.40	4.29	25.8	46.8	3.06	0.65	19.4	0.35	4.81	27.2	43.2	4.31	1.08
Tempering at 16% moisture level 2h	17.8	0.81	5.06	26.6	46.4	2.65	0.68	20.2	0.32	4.76	27.2	42.4	4.21	0.91
4h	18.0	0.28	5.14	27.0	45.8	3.32	0.46	20.0	0.34	4.24	26.1	43.2	4.70	1.42
6h	18.2	0.36	5.20	26.4	45.5	3.28	0.88	19.7	0.36	4.84	26.6	43.4	4.24	0.86
Without treatment	19.1	0.38	4.27	25.3	46.4	3.84	0.71	19.0	0.38	4.86	26.2	44.5	3.16	1.90
Whole pearl millet	18.6	0.31	4.89	26.9	44.9	3.10	1.30							

Values are means of two replicates.

Table 4.23 : Effect of storage time and temperature on the moisture content (%) of the fraction-I of pearl millet milled by barley pearler

Treatment	15 days			30 days			CD(P/ 0.05)
	25°C	30°C	35°C	25°C	30°C	35°C	
Tempering at 16% moisture level 4 h	10.0±0.04	10.1±0.05	10.1±0.06	10.0±0.04	10.1±0.02	10.4±0.06	0.02
Blanching (6 min)	9.40±0.04	9.39±0.03	9.43±0.03	9.42±0.04	9.45±0.02	9.45±0.03	0.03
Blanching (9 min)	9.56±0.03	9.59±0.04	9.60±0.02	9.58±0.02	9.60±0.04	9.62±0.06	0.03
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	9.32±0.05	9.40±0.02	9.38±0.04	9.40±0.03	9.42±0.04	9.40±0.02	0.05
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	9.04±0.03	9.40±0.02	9.06±0.04	9.12±0.03	9.09±0.04	9.06±0.04	0.02
Without treatment	8.40±0.02	8.46±0.03	8.41±0.03	8.46±0.04	8.49±0.02	8.42±0.07	0.04
Whole pearl millet	9.89±0.05	9.92±0.06	9.98±0.06	10.8±0.06	10.8±0.04	10.7±0.04	0.06
CD (P/ 0.05)	0.06	0.05	0.06	0.08	0.05	0.07	

Values are means ± SD of six determinations.

Table 4.24 : Effect of storage time and temperature on the moisture content (%) of fraction-1 of pearl millet milled by rice polisher

Treatment	15 days			30 days			CD(P/ 0.05)
	25°C	30°C	35°C	25°C	30°C	35°C	
Blanching (9 min)	9.39±0.03	9.41±0.02	9.41±0.03	9.46±0.02	9.44±0.03	9.47±0.04	0.03
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	9.40±0.02	9.39±0.03	9.38±0.03	9.40±0.02	9.46±0.04	9.45±0.03	0.02
Tempering at 14% moisture level 4h	9.66±0.03	9.67±0.04	9.68±0.04	9.69±0.03	9.70±0.02	9.76±0.04	0.02
Tempering at 16% moisture level 2h	9.60±0.03	9.65±0.03	9.65±0.08	9.66±0.05	9.60±0.04	9.70±0.07	0.04
4h	9.83±0.04	9.89±0.03	9.88±0.04	10.0±0.06	10.0±0.08	10.1±0.04	0.04
6h	9.91±0.04	9.92±0.03	10.0±0.04	10.1±0.04	10.1±0.03	10.2±0.04	0.03
Without treatment	8.49±0.06	8.51±0.05	8.53±0.03	8.60±0.05	8.60±0.02	8.59±0.03	0.04
Whole pearl millet	9.81±0.05	9.92±0.06	9.98±0.04	10.8±0.06	10.8±0.04	10.7 ±0.04	0.06
CD(P/ 0.05)	0.05	0.05	0.05	0.06	0.07	0.08	

Values are means ± SD of six determinations

Free fatty acid content of fraction increased with an increase in temperature and period of storage; storage at 35°C for 30 days produced the highest free fatty acid content of oil. Free fatty acid content was highest when fraction I from alkali-steeped blanched grains was stored at 35°C for 30 days. Tempering as well as blanching treatments increased the free fatty content of the sample to a significant extent (Table 4.25) whereas acid steeping-blanching had a significant decreasing offect. The most significant observation seemed to be the highly reduced free fatty acid content of treated as well as untreated stored samples as compared to whole pearl millet flour.

Free fatty acids of fraction I separated by rice polisher also increased with an increase in temperature and period of storage. Blanching, acid steeping-blanching and tempering increased free fatty acid content of the fraction to a significant extent (Table 4.26). whole pearl millet flour stored at 35°C for 30 days contained much more free fatty acids than fraction I obtained from treated as well as untreated pearl millet grains.

Most of lipase activity in pearl millet flour seemed to reside in fraction II separated by both, barley pearler and rice polisher (Tables 4.27 and 4.28) because the activity in fraction I was much less than 50 per cent than that in whole pearl millet. The activity in whole pearl millet seemed to be a function of temperature rather than period of storage as the activity at 35°C at both periods of storage (15 an 30 days) was two-fold the activity at 25°C.

Table 4.25 : Effect of storage time and temperature on the free fatty acid (mg/100 g fat ; as oleic acid) content of fraction-I of pearl millet milled by barley pearler

Treatment	15 days			30 days			CD(P/ 0.05)
	25°C	30°C	35°C	25°C	30°C	35°C	
Tempering at 16% moisture level 4h	359±3.54	414±3.66	482±5.40	396±2.56	432±3.52	536±4.40	4.58
Blanching (6 min)	325±2.48	361±4.64	408±3.66	366±5.40	394±5.02	502±6.56	7.84
Blanching (9 min)	328±2.89	366±2.85	402±5.42	358±5.66	388±4.78	494±7.70	10.4
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	316±5.38	360±4.72	434±6.30	366±4.82	414±3.78	510±6.22	7.88
Alkali (0.5% $Ca(OH)_2$ steeping for 6 h and blanching for (9 min)	356±5.10	402±4.32	486±6.61	368±3.35	436±5.25	545±6.18	8.37
Without treatment	296±3.42	316±2.85	352±4.84	312±2.98	342±3.54	430±5.41	6.40
Whole pearl millet	821±6.26	1260±10.4	1790±9.88	1140±6.91	1940±5.45	2420±8.12	16.2
CD (P/ 0.05)	6.41	5.40	7.82	4.68	9.10	12.6	

Values are means ± SD of four determinations

Table 4.26 : Effect of storage time and temperature on the free fatty acid (mg/100 g fat ; as oleic acid) content of fraction -I of pearl millet milled by rice polisher

Treatment	15 days			30 days			CD(P/ 0.05)
	25°C	30°C	35°C	25°C	30°C	35°C	
Blanching (9 min)	290±3.38	338±4.27	372±4.18	322±2.90	364±3.76	408±5.44	7.42
Acid (0.1N HCl) steeping for 6 h and blanching (9 min)	332±5.28	410±2.82	418±3.42	368±3.10	450±4.22	468±6.20	8.18
Tempering at 14% moisture level 4 h	300±2.74	320±3.48	358±4.76	336±3.28	368±4.12	385±2.16	6.14
Tempering at 16% moisture level 2 h	281±3.35	308±2.22	376±4.12	302±3.16	330±4.52	380±5.12	5.80
4 h	290±3.66	318±4.02	384±3.96	315±3.85	344±2.55	402±5.15	5.02
6 h	288±3.08	310±2.05	376±4.16	312±2.44	354±4.23	412±3.85	4.56
Without treatment	308±2.42	338±4.16	362±3.60	348±3.39	368±436	426±4.42	7.02
Whole pearl millet	821±6.26	1260±10.4	1790±9.88	1140±6.91	1940±5.45	2420±8.12	16.2
CD (P/ 0.05)	5.38	4.66	6.82	5.70	6.16	9.65	

Values are means ± SD of four determinations

Table 4.27 : Effect of storage time and temperature on the lipase activity* of fraction-I of pearl millet milled by barley pearler

Treatment	15 days			30 days			CD(P/ 0.05)
	25°C	30°C	35°C	25°C	30°C	35°C	
Tempering at 16% moisture level 4h	8.55±0.26	9.86±0.28	11.5±0.34	9.43±0.14	10.3±0.40	12.8±0.41	0.25
Blanching (6 min)	7.90±0.23	8.78±0.32	10.2±0.31	8.90±0.20	9.59±0.33	12.2±0.20	0.28
Blanching (9 min)	8.08±0.20	9.01±0.16	9.90±0.21	8.82±0.24	9.55±0.48	12.2±0.24	0.24
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	8.12±0.18	9.25±0.26	11.2±0.20	9.41±0.12	10.6±0.34	13.1±0.18	0.30
Alkali (0.5% $Ca(OH)_2$ steeping for 6 h and blanching for (9 min)	8.16±0.22	9.22±0.18	11.1±0.24	8.44±0.23	10.0±0.21	12.5±0.36	0.42
Without treatment	8.45±0.12	9.02±0.28	10.8±0.30	8.91±0.33	9.77±0.18	12.3±0.50	0.32
Whole pearl millet	13.6±0.49	20.8±1.46	32.9±0.84	18.8±0.52	32.1±0.88	40.0±1.03	1.72
CD (P/ 0.05)	0.21	0.40	0.23	0.58	0.32	0.36	

Values are means ± SD of four determinations

* Per cent fat activity on per cent fat basis.

Table 4.28 : Effect of storage time and temperature on the lipase activity* of fraction-1 of pearl millet milled by rice polisher

Treatment	15 days			30 days			CD(P/ 0.05)
	25°C	30°C	35°C	25°C	30°C	35°C	
Blanching (9 min)	8.28±2.46	9.65±0.43	10.6±0.13	9.20±0.68	10.4±0.60	11.6±0.40	0.71
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	8.04±0.27	9.93±0.46	10.1±0.51	8.91±0.29	10.9±0.50	11.3±0.28	0.48
Tempering at 14% moisture level 4 h	8.72±0.15	9.30±0.16	10.4±0.22	9.77±0.38	10.7±0.32	11.1±0.54	0.36
Tempering at 16% moisture level 2 h	8.38±0.35	9.19±0.26	11.2±0.24	9.01±0.29	9.85±0.30	11.3±0.44	0.34
4 h	8.76±0.46	9.60±0.31	11.3±0.45	9.52±0.43	10.4±0.21	12.2±0.56	0.44
6 h	8.92±0.38	9.60±0.36	11.2±0.46	10.2±0.56	11.0±0.15	12.8±0.59	0.58
Without treatment	8.68±0.32	9.52±0.28	10.2±0.34	9.80±0.44	10.4±0.22	12.0±0.38	0.40
Whole pearl millet	13.6±0.49	20.8±1.46	32.9±0.84	18.8±0.52	32.1±0.88	40.0±1.03	1.72
CD (P/ 0.05)	0.12	0.52	0.79	0.58	0.50	0.70	

Values are means ± SD of four determinations.

*Per cent fat activity on per cent fat basis

Lipase activity increased significantly when fraction II was separated by barley pearler after tempering, blanching for 6 min, acid steeping-blanching and alkali-steeping blanching and stored at 25°C for 15 days. Activity in these treated samples rose as the temperature and period of storage was raised; temperature had a greater impact on the lipase activity of treated samples.

After 15 days of storage at 25°C in all the treated samples except the acid steeped-blanched lipase activity in fraction I separated by rice polisher increased to a greater extent; highest was observed in 9 min blanching (Table 4.28). In the same way as in barley pearler, fraction I separated by rice polisher after different treatments showed the same lipase activity under different temperature and storage conditions.

Fat acidity in whole pearl millet flour was a little higher than that in fraction I separated by both rice polisher and barley pearler with or without treatments of grain (Table 4.29 and 4.30). As the time and temperature of storage were raised, fat acidity in fraction I of treated as well as untreated samples increased significanly. Temperature seemed to have greater effect on increasing fat acidity than period of storage.

Peroxide value at zero period of storage in whole pearl millet and fraction I of treated and untreated grains separated by barley pearler and rice polisher ranged from 3.08 to 5.78 per cent and 4.04 to 4.78 meq/kg fat, respectively (Tables 4.31 and

Table 4.29 : Effect of storage time and temperature on the fat acidity (mg KOH/100 g flour) value of fraction-I of pearl millet milled by barley pearler

Treatment	Fresh	15 days			30 days			
		25°C	30°C	35°C	25°C	30°C	35°C	CD(P/ 0.05)
Tempering at 16% moisture level 4h	17.4±0.28	23.1±0.55	25.8±0.15	34.8±0.51	31.6±1.06	38.2±0.67	43.4±0.29	0.91
Blanching (6 min)	16.6±0.35	23.8±0.20	27.2±0.42	33.9±0.28	30.4±0.28	36.3±0.44	40.1±0.33	0.56
Blanching (9 min)	16.8±0.12	23.2±0.32	29.0±0.19	35.1±1.54	31.1±1.50	37.3±0.82	41.8±0.29	0.99
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	17.1±0.34	22.5±0.38	29.3±0.22	40.0±0.43	28.9±0.56	36.4±0.41	44.2±1.70	0.89
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	16.6±0.44	23.3±0.34	25.6±0.37	33.1±0.48	28.9±0.29	34.5±1.14	39.3±0.35	0.86
Without treatment	16.8±0.67	23.1±0.78	24.3±0.33	31.8±0.70	28.9±0.31	32.5±0.10	37.8±0.55	0.99
Whole pearl millet	19.4±0.76	33.2±0.66	35.7±0.25	50.7±1.97	45.9±0.91	42.3±1.26	66.7±1.71	1.64
CD (P / 0.05)	0.32	0.96	0.52	0.92	0.65	1.30	1.22	

Values are means ± SD of four determinations.

Table 4.30 : Effect of storage time and temperature on the fat acidity (mg KOH/100 g flour) value of fraction-I of pearl millet milled by rice polisher

Treatment	Fresh	15 days			30 days			CD(P/0.05)
		25°C	30°C	35°C	25°C	30°C	35°C	
Blanching (9 min)	16.5±0.24	22.1±0.26	25.5±0.67	29.9±0.50	30.5±0.70	33.5±0.52	36.0±0.45	0.88
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	17.3±0.85	24.0±0.20	29.4±0.56	30.4±0.87	32.0±0.71	39.3±0.74	41.6±0.83	1.04
Atempering at 14% moisture level 4 h	16.1±0.46	22.0±0.25	23.9±0.57	26.1±0.97	28.1±0.64	36.3±0.73	37.2±0.69	1.09
Tempering at 16% moisture level 2h	16.1±0.32	21.2±0.16	23.6±0.83	26.2±0.85	27.4±1.10	34.8±0.46	35.7±0.97	1.14
4h	16.2±0.48	22.2±0.35	25.0±0.78	27.9±0.39	29.3±0.67	35.3±0.46	37.8±0.55	0.82
6h	16.4±0.41	23.6±0.30	25.8±0.88	28.9±0.50	31.1±0.88	36.0±0.62	38.2±0.90	1.08
Without treatment	16.7±0.54	22.0±0.72	23.3±0.58	24.6±0.42	28.4±0.78	31.8±0.72	33.1±0.93	1.12
Whole pearl millet	19.4±0.76	33.2±0.66	35.7±0.25	50.7±1.97	45.9±0.91	42.3±1.26	66.7±1.71	1.64
CD (P/ 0.05)	0.40	0.58	1.00	1.25	1.20	1.08	1.23	

Values are means ± SD of four determinations.

Table 4.31 : Effect of storage time and temperature on the peroxide value (meq/kg fat) of fraction I of pearl millet milled by barley pearler

Treatment	Fresh	15 days			30 days			CD(P/0.05)
		25°C	30'C	35°C	25°C	30'C	35°C	
Tempering at 16% moisture level 4 h	3.80±0.14	12.7±0.44	14.3±0.40	14.3±0.48	19.5±0.98	16.8±0.41	19.6±0.61	0.88
Blanching (6 min)	3.36±0.25	9.27±0.15	14.8±0.32	16.4±0.35	14.4±0.34	17.2±0.58	13.1±0.32	0.59
Blanching (9 min)	3.14±0.18	9.46±0.20	13.6±0.74	17.4±0.41	14.4±16.2	16.2±0.30	15.8±0.26	0.61
Acid (0.2N HCl) steeping for 4 h and blanching (9 min)	3.84±0.34	8.78±0.40	11.0±0.43	13.8±0.41	13.8±0.32	15.0±0.27	15.4±0.42	0.58
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	3.62±0.28	9.20±0.33	11.4±0.39	14.3±0.71	13.5±0.38	14.4±0.40	16.0±0.42	0.76
Without treatment	3.96±0.26	9.40±0.36	13.2±0.52	14.9±0.76	13.2±0.16	14.8±0.32	15.3±0.57	0.72
Whole pearl millet	5.78±0.36	17.5±0.25	20.4±0.46	21.6±0.90	29.1±0.27	30.4±0.41	38.5±1.04	1.06
CD (P/ 0.05)	0.36	0.45	1.09	0.87	0.63	0.85	1.05	

Values are means ± SD of four determinations.

4.32). Peroxide value increased with increase in time and temperature of storage in all the samples; increase in whole pearl millet grain was greater than other samples. Increase in peroxide value seemed to be more a function of time than temperature of storage. Alkali-blanching and tempering at 16 per cent moisture level for 4 h in case of fraction I separated by barley pearler and tempering at 14 and 16 per cent moisture level for 4 h in case of rice polisher seemed to increase peroxide value to a significant extent when the samples were stored at 35°C for 30 days.

Whole pearl millet flour contained higher lipoxygenase activity than fraction I of treated and untreated samples separated by barley pearler and rice polisher (Tables 4.33 and 4.34). After 30 days of storage all the samples had an increased lipoxygenase activity when the samples were stored at 25, 30 and 35°C; the increase was highest at 35°C. Stored whole pearl millet flour had much higher activity than fraction I.

Aroma, an important sensory attribute of acceptability of pearl millet flour deteriorated as fraction I of treated and untreated grains separated by barley pearler and rice polisher as well as whole pearl millet flour was stored; higher the temperature and longer the period of storage, greater was the deterioration (Tables 4.35 and 4.36). As a results of 30 days storage at 35°C whole pearl millet flour was disliked moderately, whereas flour of blanching, tempering and untreated grain was 'liked moderately'.

Table 4.32 : Effect of storage time and temperature on the peroxide value (meq/kg fat) of fraction-I of pearl millet milled by rice polisher

Treatment	Fresh	15 days			30 days			CD(P/ 0.05)
		25°C	30°C	35°C	25°C	30°C	35°C	
Blanching (9 min)	3.08±0.34	8.30±0.64	9.85±0.25	9.90±0.24	13.1±0.34	12.8±0.42	14.9±0.30	0.58
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	3.80±0.42	8.80±0.57	10.1±0.36	10.6±0.66	13.9±0.38	16.7±0.60	14.8±0.41	0.78
Tempering at 14% moisture level 4 h	3.76±0.28	8.20±0.30	10.3±1.20	12.2±0.31	12.7±0.38	13.7±0.25	15.1±0.35	0.85
Tempering at 16% moisture level 2h	3.85±0.28	8.95±0.10	9.90±0.34	11.0±0.28	12.7±0.38	14.4±0.31	14.4±0.51	0.52
4h	3.88±0.25	9.20±0.52	9.40±0.35	12.4±0.16	12.6±0.61	14.1±0.38	15.1±0.18	0.64
6h	4.04±0.32	9.71±0.40	9.90±0.56	12.7±0.40	13.1±0.52	14.0±0.12	14.8±0.48	0.70
Without treatment	3.87±0.44	8.20±0.52	9.66±0.50	9.85±0.62	11.4±0.32	12.8±0.60	13.9±0.34	0.78
Whole pearl millet	5.78±0.36	17.5±0.25	20.4±0.46	21.6±0.90	29.1±0.27	30.4±0.41	38.5±1.04	1.06
CD(P/ 0.05)	0.55	0.67	0.85	0.64	0.91	1.48	0.96	

Values are means ± SD of four determinations.

Table 4.33 : Effect of storage time and temperature on the lipoxygenase activity (ul of O_2/g/min) of fraction-I of pearl millet milled by barley pearler

Treatment	30 days				
	Fresh	25°C	30°C	35°C	CD (P/ 0.05)
Tempering at 16% moisture level 4h	0.67±0.04	0.70±0.05	0.76±0.06	0.93±0.13	0.12
Blanching (6 min)	0.61±0.04	0.65±0.03	0.61±0.03	0.67±0.03	0.06
Blanching (9 min)	0.61±0.04	0.66±0.05	0.72±0.04	0.70±0.05	0.09
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	0.58±0.03	0.62±0.05	0.77±0.06	0.80±0.10	0.14
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	0.64±0.06	0.67±0.06	0.62±0.04	0.72±0.05	0.10
Without treatment	0.63±0.03	0.68±0.04	0.69±0.06	0.78±0.13	0.08
Whole pearl millet	1.56±0.07	3.52±0.11	3.93±0.08	4.08±0.06	0.17
CD (P/ 0.05)	0.08	0.08	0.06	0.08	

Values are means ± SD of three determinations.

Table 4.34 : Effect of storage time and temperature on the lipoxygenase activity (ul of O_2/g/min) of fraction-1 of pearl millet milled by rice polisher

Treatment	30 days				
	Fresh	25°C	30°C	35°C	CD (P / 0.05)
Blanching (9 min)	0.51±0.03	0.58±0.04	0.54±0.03	0.64±0.05	0.04
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	0.62±0.03	0.66±0.08	0.72±0.07	0.71±0.03	0.08
Tempering at 14% moisture level 4h	0.55±0.04	0.57±0.03	0.60±0.03	0.61±0.04	0.05
Tempering at 16% moisture level 2h	0.57±0.06	0.58±0.03	0.62±0.06	0.64±0.04	0.07
4h	0.52±0.03	0.57±0.03	0.57±0.04	0.68±0.04	0.04
6h	0.54±0.05	0.58±0.02	0.61±0.04	0.56±0.05	0.04
Without treatment	0.58±0.06	0.66±0.05	0.64±0.03	0.72±0.07	0.06
Whole pearl millet	1.56±0.07	3.52±0.11	0.39±0.08	4.08±0.06	0.17
CD (P/ 0.05)	0.07	0.08	0.08	0.09	

Values are means ± SD of three determinations.

Table 4.35 : Effect of storage time and temperature on the aroma of fraction-I of pearl millet milled by barley pearler *

Treatment	Fresh	15 days			30 days		
		25°C	30°C	35°C	25°C	30°C	35°C
Tempering at 16% moisture level 4h	6.0	5.0	5.0	4.5	4.8	4.7	3.5
Blanching (6 min)	6.0	6.0	5.4	5.0	5.0	4.5	4.0
Blanching (9 min)	6.0	5.4	5.0	5.0	4.5	4.2	4.0
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	4.0	4.0	3.0	3.0	3.2	2.8	2.8
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	5.0	5.0	5.0	4.5	4.0	4.0	3.5
Without treatment	6.0	5.4	5.0	5.0	5.0	4.8	4.4
Whole pearl millet	6.0	3.5	3.0	3.0	2.8	2.4	2.0

* Average score given by 10 judges in 6-point hedonic scale

Table 4.36 : Effect of storage time and temperature on the aroma of fraction-I of pearl millet milled by rice polisher*

Treatment	Fresh	15 days			30 days		
		25°C	30°C	35°C	25°C	30°C	35°C
Blanching (9 min)	6.0	5.0	4.5	4.0	4.0	4.0	3.8
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	4.5	4.2	4.5	4.5	4.0	4.4	4.0
Tempering at 14% moisture level 4h	6.0	5.0	5.0	4.2	5.0	4.4	3.5
Tempering at 16% moisture level 2h	6.0	6.0	5.5	4.5	5.6	4.0	4.2
4h	6.0	5.4	5.0	4.0	5.0	4.0	3.5
6h	6.0	5.0	5.0	4.7	5.0	4.0	3.8
Without treatment	6.0	5.0	4.8	4.5	5.0	4.5	4.0
Whole pearl millet	6.0	3.5	3.0	3.0	2.8	2.4	2.0

* Average score given by 10 judges in 6-point hedonic scale

Improved keeping quality of pearl millet after milling by barley pearler and rice polisher as compared to whole pearl millet flour was, perhaps, due to removal of a major portion of fat rich germ and aleurone layers during milling as well as low moisture content. It appeared from the results that the lipase and lipxygenase activity of pearl millet existed in fraction II which is comprised of bran and germ. These enzymes are responsible for increase in free fatty acid content, fat acidity and peroxide value. Lai and Varriano-Marston (1980) in their histochemical studies on pearl millet also indicated that lipase activity was located mainly in the germ, pericarp, and aleurone and subaleurone layers. Perten et al. (1983) also suggested decortication of pearl millet approximately to 20 per cent for keeping it for several months. Deterioration of pearl millet flour with increase in temperature and time was found parallel with decrease in its acceptability of aroma. Patel and Parameshwarn (1992) found that the lipase activity as well as free fatty acid levels of pearl millet not only increased during storage but also showed high fluctuations.

4.5 Product development and organoleptic evaluation

The fraction I obtained after milling of pearl millet grains by barley pearler and rice polisher was used for preparing different recipes. Their acceptability in terms of color, flavour, taste, appearance, bitterness, sources and texture was adjudged by a panel. The average values for overall acceptability are given in Tables 4.37 and 4.38.

Table 4.37 : **Overall acceptability of the products, khichdi, porridge, chapati, biscuits and cake prepared from the stored fraction-I of pearl millet milled by barley pearler***

Treatment	Khichdi	Porridge	Chapati	Biscuits	Cake
Tempering at 16% moisture level 4h	7.0±0.22	7.0±0.14	7.0±0.09	7.1±0.12	7.7±0.04
Blanching (6 min)	7.2±0.37	7.2±0.18	7.4±0.18	6.8±0.24	8.0±0.08
Blanching (9 min)	7.4±0.07	7.4±0.08	7.6±0.24	7.0±0.04	8.1±0.06
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	6.0±0.18	6.6±0.04	6.0±0.06	7.0±0.24	6.9±0.21
Alkali [0.5% $Ca(OH)_2$] steeping for 6 h and blanching (9 min)	7.0±0.14	7.6±0.10	7.0±0.08	7.2±0.28	7.8±0.09
Without treatment	7.1±0.32	7.6±0.26	7.5±0.16	7.0±0.09	7.4±0.14
Whole pearl millet (fresh)	6.7±0.28	6.2±0.12	7.0±0.18	7.0±0.08	6.8±0.06
CD(P/)	0.12	0.18	0.04	0.08	0.06

* Average score of five characteristics (colour, appearance, flavour, texture and taste) given by 10 judges in 9-point hedonic scale.

Table 4.38 : Overall acceptability of the products, khichdi, porridge, chapati, biscuits and cake prepared from the stored fraction-I of pearl millet milled by rice polisher*

Treatment	Khichdi	Porridge	Chapati	Biscuits	Cake
Blanching (9 min)	6.8±0.11	7.5±0.09	7.1±0.18	7.1±0.06	7.5±0.04
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	6.5±0.23	6.6±0.34	6.0±0.26	6.8±0.14	6.6±0.09
Tempering at 14% moisture level 4h	7.1±0.08	7.5±0.12	7.1±0.24	6.8±0.19	7.5±0.12
Tempering at 16% moisture level 2h	6.9±0.21	7.4±0.16	7.0±0.32	6.6±0.18	7.5±0.14
4h	7.0±0.05	7.6±0.08	7.0±0.30	6.7±0.37	7.5±0.11
6h	6.7±0.16	7.4±0.09	6.8±0.24	7.0±0.06	7.4±0.08
Without treatment	7.1±0.07	8.0±0.8	7.0±0.14	7.1±0.20	7.8±0.16
Whole pearl millet (Fresh)	6.7±0.28	6.2±0.12	7.0±0.18	7.0±0.08	6.8±0.06
CD (P/ 0.05)	0.08	0.18	0.08	0.07	0.04

* Average score of five characteristics (colour, appearance, flavour, texture and taste) given by 10 judges in 9-point hedonic scale.

Khichri made from acid steeped-blanched grains had the lowest acceptability among all treated as well as untreated grains, may be because of a little sour taste. Khichri made from other samples was moderately liked.

Sensory quality of porridge was found to be significantly improved with milling of treated as well as untreated grains. Chapaties prepared from all the samples except acid-steeped blanched were found acceptable.

Biscuits and cakes were more acceptable when made from milled samples than whole pearl millet flour. Blanching of grains prior to milling increased theacceptability of cakes. Cakes prepared from blanched sample came in 'very much liked' category whereas those prepared from acid steeped blanched came in 'moderately liked' category.

Overall acceptability results showed that products made from fraction I after milling of treated and untreated grains by barley pearler and rice polisher were acceptable.

SUMMARY AND CONCLUSION

Pearl millet is an important crop of semi-arid and arid regions of India. On account of its limited uses, preference of consumers for other cereals lack of sound procurement policy etc. pearl millet grain is underutilised. All this results in poor returns to the growers. Besides, being a source of protein, energy and minerals pearl millet grain is a very good source of fat (4.5 to 9.6 per cent), most of which resides in germ. The grain can be stored for longer time without damaging its keeping quality but whole grain flour develops rancidity rapidly upon storage at room temperature. Lipase and lipoxygenase activity also reside in germ.

without damaging its

. The germ can not only be used as a source of edible oil but its separation from the grain may impa longer shelflife to the flour made from degermed grain.

Sixty strains/varieties of pearl millet were screened for fat content which ranged from 4.5 to 9.6 per cent. HC-4, a pearl millet cultivar of Haryana, was milled by Strong Scott barley pearler, McGill rice polisher, Sataka rice machine and Tangential Abrasive Dehulling Device (TADD) using different scouring periods. Milling on TADD and Satake rice machine was not successful.

Pearl millet grain was given different treatments for studying the recovery and fat content of milled fractions. The treatments included tempering at 12, 14 and 16 per cent moisture level for 2, 4 and 6 h, blanching for 3, 6 and 9 min, alkali (0.5% $Ca(OH)_2$) and acid steeping (0.2N HCl) for 6 h followed by blanching (3, 6 and 9 min).

Scouring time for barley pearler was 2, 4, 6 and 8 min and 1,2,3 and 4 min for rice polisher. The fractions separated by these two mills were designated as fraction I and II. Bran, germ, aleurone layer and some part of endosperm formed fraction II. Fraction-I comprised of mainly endosperm and some leftover bran, germ and aleurone layer. The untreated pearl millet grains were milled by both barley pearler and rice polisher; as scouring time increased recovery of fraction-I decreased and fat content in fraction-II increased.

In barley pearler, grains after tempering, blanching, steeping and blanching showed almost the same trend in per cent recovery and fat content (%) of milled fractions as untreated grains. At every moisture level i.e. 12, 14 and 16 per cent an increase in tempering period resulted in lower recovery of fraction-I at a fixed scouring time. There was a gradual decrease in fraction-I recovery with an increase in scouring time at every moisture level and tempering period. The highest recovery was found in 0.5 per cent $Ca(OH)_2$ steeping (6 h) with 9 min blanching. In rice polisher the recovery (%) did not improve by increasing

the moisture level from 12 to 16 per cent. But steeping in 0.2N HCl improved the recovery (%). Per cent recovery of fraction-I decreased and that of fraction-II increased as milling time was increased from 1 to 4 min. A rise in moisture level from 12 to 16 per cent resulted in decrease of fat contents in fraction-I and increase of that in fraction-II. Per cent recovery and fat of fraction-I decreased following an increase in tempering period at every moisture level. Six and three min scouring time for barley pearler and rice polisher, respectively removed about 50 per cent fat in fraction II of untreated grains. But treatments of the grains were not found helpful in diverting a greater amount of fat in fraction-II. Similarly, fraction-I contained more than 50 per cent mineral matter present in the grains milled by barley pearler and less than 50 per cent in grains milled by rice polisher. Fraction I after lime steeping and blanching was containing highest total ash content. Higher concentration of ash in fraction II milled by both barley pearler and rice polisher is attributable to the bran part of grain.

Milling of treated as well as untreated grains by barley pearler and rice polisher produced fraction I containing greater proportion of total protein of grain in it and fraction II had highest concentration of protein. Most of the crude protein was present in both the fractions in the form of true protein. Fraction II from alkali steeped and blanched grains in case of barley pearler and acid steeped and blanched grains in rice polisher

contained highest concentration of protein. Milling both by barley pearler and rice polisher could divert only a minor proportion of total starch in fraction II. Fraction I on the other hand contained most of the starch present in whole grain. Concentration of total soluble and non-reducing sugars was by and large same in both the fractions but since fraction I formed a major portion of the grain, more than 80 and 70 per cent sugars remained in fraction I of barley pearler and rice polisher, respectively.

Milling by barley pearler and rice polisher of pearl millet grains separated polyphenols and phytic acid in fraction I and fraction II. Fraction II milled by barley pearler and rice polisher contained about 72 and 65 per cent polyphenols and 40 and 54 per cent phytic acid, respectively. Fraction I of acid steeped and blanched grains had lowest concentration of polyphenols and phytic acid. Hydrochloric acid was found to be an effective blanching agent which removed polyphenols in pearl millet grains.

Fraction I, rich in mineral matter and separated both by barley pearler and rice polisher, contained half of Ca, P, Zn and Fe of total grains. But more than 60 per cent of total HCl-extractable Ca, P, Zn and Fe resided in this fraction from treated as well as untreated grains. The extractability of these minerals in fraction I was greater than in whole pearl millet.

In vitro protein and starch digestibility of fraction I of treated as well as untreated grains milled by both barley pearler and rice polisher were significantly than those of whole pearl

millet grains. Though fraction II was rich in protein but it had low protein digestibility. Blanching and acid steeping blanching increased whereas alkali steeping and tempering did not change true protein digestibility. On the other hand starch digestibility increased by acid steeping-blanching and did not change significantly by 6 min blanching.

Whole pearl millet grains were found to contain about 45 per cent linoleic acid. Oleic and palmitic acid were other major fatty acids. Milling by both barley pearler and rice polisher marginaly changed the fatty acid composition in fraction I and fraction II. Linoleic acid was major fatty acid in both the fractions.

Fraction I obtained after milling of treated and untreated grains of pearl millet by barley pearler and rice polisher had longer shelf life than whole pearl millet flour. The aroma of fraction I obtained after all different treatments was acceptable. Storage did not adversely affect the aroma of flour made from fraction I after different treatments. Free fatty acids, lipase activity, fat acidity and peroxide value were significantly lower in fraction I than whole pearl millet flour at all temperatures and time periods. Fraction I did not contain significant lipoxygenase activity and it remains limited in fraction II. Organoleptic quality of Khichdi, porridge, chapati, biscuits and cake made from fraction-I milled by these instruments was better than that of the products made from whole pearl millet flour.

Machines like barley pearler and rice polisher can be employed for milling pearl millet grains. Treatments prior to milling could manoeuvred distribution of nutrients and antinutrients into different fractions. As fraction II representing bran and germ contained a major part of fat, antinutrients and rancidity causing factors, its removal by milling operations yielded fraction I which had better nutritional value and longer shelflife. The milling, therefore, offers scope not only for improving nutritional quality and storability but also several sensory attributes of pearl millet grain. Fraction II being rich in oil having a desirable fatty acid profile can be used as a source of edible oil. More intensive investigations are required to be undertaken for developing a milling system for exclusive separation of germ and bran from endosperm so that the grain components could be put to most effective utilisation of the underutilized grain.

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Appendix -I

Fat content (g/100 g) of pearl millet strains/cultivars

Sr.No.	Name of variety	Fat content
1.	1317/213	7.22
2.	126	6.34
3.	81B x 2014/207 tall	4.84
4.	1768/216	6.34
5.	77/170 x 77/248	5.12
6.	2240/224	5.94
7.	1201/213	7.44
8.	29-11-2/486	6.02
9.	904-1-2-2-2/221	5.04
10.	18-7-3/141	4.83
11.	VCF4-2661-5	7.52
12.	77/337-1-4-3	6.60
13.	IVS-154-2-1-2 (D_2 dwarf)	6.50
14.	ICR-170	6.70
15.	VCF_4-827	9.30
16.	ICR-151	7.10
17.	833-2	6.80
18.	90/4-5	6.60
19.	HHB-67 F_2	8.80
20.	HHB 60 F_2	8.20
21.	HHB 68 F_2	8.10
22.	HHB 50 F_2	8.60
23.	77/144	7.21
24.	ICMR-1500	7.00
25.	VCF_6 62-1-2 /236	9.10
26.	VCF_6 - 874	7.60
27.	VCF_4-264-1/381	6.20
28.	77/371-307	7.40
29.	ICR 202 (Medium)	9.60
30.	CVJ-1-2-1-22 321	6.30

Appendix-I contd.....

Sr.No.	Name of variety	Fat content
31.	INB 439	7.10
32	VC 1197-3-14	6.60
33.	INB-486	6.40
34.	ICMPS-500-3-2	7.52
35.	30-25-1-1	6.20
36.	77/8-9-3-5	5.20
37.	717-2-2-1-14-2/579	7.00
38.	INB 87/74-10	8.70
39.	INB 87/74-61	8.20
40.	VCF_4-2224	6.40
41.	77/122-5-9-2-1-2/304	7.00
42.	VCF_6-869	8.00
43.	77/248-2-5-1	5.90
44.	VCF_4-2366	6.50
45.	77/317 -4-3-3-4 322 tall	8.20
46.	INB-629	5.00
47.	ICR 212/48 tall	6.60
48.	VCF_4 2245/185 tall	6.50
49.	77/360-1-3	6.90
50.	ICR-142 P	5.40
51.	7-2-2-5-5-1 487-88	5.30
52.	VCF_4 1864 tall	7.31
53.	1275 (+) tall	5.60
54.	INB 759/195	9.60
55.	INB -488	5.80
56.	77/273	6.40
57.	INB-689/3	7.00
58	1275/11	7.40
59.	G-73-107/555	7.50
60.	HC-4	7.72

Appendix -II

Score sheet for taste panel/data under Hedonic scale

Name _____

Product _____

Test these samples and check how much you like or dislike each one Use appropriate scale to show your attitude by assessing points that best describe your feeling about the sample. An honest expression of your feeling will help to obtain unbiased data

Code No.	Colour	Aroma	Overall acceptability	Total remarks

Rate	Organoleptic Score
Like Extremely	6
Like very much	5
Like moderately	4
Neither like nor dislike	3
Dislike moderately	2
Dislike very much	1
Dislike extremely	0

Signature

Appendix -III

Score sheet for taste panel/data under hedonic scale

Name _____

Product _____

Dated :

Test these samples and check how much you like or dislike each one. Use appropriate scale to show your attitude by assigning points that best describe your feeling about the sample. An honest expression of your feeling will help us

Code No.	Colour	Appearance	Flavour	Texture	Taste	Overall acceptability	Total	remarks

Rate	Organoleptic scope
Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

Note : Please rinse your mouth before and after tasting each product.

Signature

Effect of milling by barley pearler on HCl-extractability (%) of Calcium (Ca), Phosphorus (P), Iron (Fe) and Zinc (Zn) of the fractions of pearl millet

Treatment	Fraction-I				Fraction-II			
	Ca	P	Fe	Zn	Ca	P	Fe	Zn
Tempering at 16% moisture level 4h	46.0	42.1	28.6	53.9	13.2	11.6	8.62	19.2
Blanching (6 min)	56.1	45.8	31.2	58.8	10.5	11.4	8.62	18.5
Blanching (9 min)	58.1	47.8	33.5	62.3	11.4	11.5	8.53	17.6
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	57.2	55.4	35.4	60.9	14.4	12.0	10.3	20.3
Alkali (0.5% $Ca(OH)_2$ steeping for 6 h and blanching (9 min)	44.3	40.4	25.3	50.4	28.9	10.9	8.74	16.7
Without treatment	54.0	46.5	30.7	58.4	13.2	11.0	8.03	17.5
Whole pearl millet	31.8	28.1	18.0	36.7				

Values are means of four determinations.

Appendix-V

Effect of milling by rice polisher on HCl-extractability (%) of Calcium (Ca), Phosphorus (P), Iron (Fe) and Zinc (Zn) of the fractions of pearl millet

Treatment	Fraction-I				Fraction-II			
	Ca	P	Fe	Zn	Ca	P	Fe	Zn
Blanching (9 min)	57.1	53.4	34.0	64.6	19.1	13.3	8.17	19.4
Acid (0.2N HCl) steeping for 6 h and blanching (9 min)	54.3	53.9	27.4	67.6	18.4	14.7	10.1	20.0
Tempering at 14% moisture level 4h	55.2	48.4	33.1	60.0	18.0	12.7	8.38	18.5
Tempering at 16% moisture level 2h	50.1	47.9	30.0	56.4	20.0	12.9	8.00	20.3
4h	53.6	50.1	31.0	59.8	18.8	12.5	8.03	18.8
6h	56.9	52.6	33.0	61.9	18.0	11.6	9.00	18.1
Without treatment	53.2	46.4	30.0	55.0	16.7	12.1	8.60	19.6
Whole pearl millet	31.8	28.1	18.0	36.7				

Values are means of four determinations.