CERTIFICATE

Kum Sarbani Roy has satisfactorily prosecuted the course of research and that the thesis entitled 'Protein and Energy Availability of Processed Sorghum Products' submitted is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that the thesis or part thereof has not been previously submitted by her for a degree of any University.

Date: 1.4.85

Pushpamma

Major Adviser

CERTIFICATE

This is to certify that the thesis entitled 'Protein and Energy Availability of Processed Sorghum Products' submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Home Science of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Kum Sarbani Roy under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree of diploma or has been published. Published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by her.

Chairman of the Advisory Committee

Thesis approved by the Student Advisory Committee

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Sarbani Roy

(SARBANI ROY)

ABSTRACT

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Sorghum is the fifth most important cereal crop in the world. It is the principal source of calories and provides a major source of protein in the diets of the millions of people living in the semi arid tropics. However, the optimum utilization of this source of nutrients present in sorghum grain is complicated by various factors. The objective of this study was to observe the effect of processing on the availability of protein and energy from sorghum grain.

Sorghum grain was subjected to primary processing, that is, dehulling by traditional and mechanical method. The common traditional dehulling method practised in Andhra Pradesh was followed. The PRL mini dehuller was used for mechanical dehulling.

The dehulled grains were analyzed for proximate and amino acid composition, *in vitro* digestibility, by enzymatic assay and bioavailability studies by rat feeding trials. Statistical analysis was done to find the least significant difference at 5% level and correlation coefficients of various parameters were determined.

It was found that on dehulling the protein, fat, ash and fibre levels were reduced significantly and starch levels were significantly increased. Between the dehulling methods it was observed that when values were expressed on a percent basis there was no significant differences in protein, fibre and starch values, and ash and fat levels in traditionally dehulled flour, were significantly lower.

Lysine was the amino acid most affected on dehulling. On traditional dehulling the loss was 21% and a 16.5% loss was observed on mechanical dehulling. The other amino acids were not affected to any great extent.

In vitro starch digestibility showed a significant increase on dehulling and mechanical dehulling had a slightly higher starch digestibility than traditional dehulling though this increase was not significant. *In vitro* protein digestibility also showed a significant increase on dehulling. The traditionally dehulled flour had a higher protein digestibility value than mechanically dehulled flour but again this increase was not significant.

Bioavailability studies with whole and dehulled grain indicated that, whole grain diet when fed to rats resulted in higher NPU values and increased weight gain, than dehulled grain diets. The true protein digestibility, digestible energy and dry matter digestibility values, however were higher in the dehulled grain diets. There was no significant difference in NPU or digestibility values between the traditionally and mechanically dehulled grain diets.

Based on these finding further study was carried out with various sorghum products like parched, popped, malted, germinated, boiled, baked and fermented. Whole and mechanically dehulled sorghum grain were used in the preparation of the products as mechanically and traditionally dehulled grain did not display any marked differences in *in vitro* and *in vivo* assays.

All the products were again analyzed as for whole and dehulled grain previously (proximate analysis, amino acid composition, *in vitro* assay and bioavailability studies). Differences were observed in the proximate composition of the sorghum products. Protein, fat and fibre contents decreased in a number of products. Germination resulted in a slight increase in protein content but it was not significant. Starch content of the products were low when compared to untreated grain, fermented products had the lowest starch content. Starch contents of most dehulled grain products were significantly higher than whole grain products.

In the sorghum products, again, lysine was the amino acid most affected. A 28% decrease was observed on popping and 39% in baking (biscuits). In the other treatments the loss ranged from 4%-20%. Methionine + cystine values were affected in dosa where about 11-20% loss was observed, and in biscuits the loss was 16%.

Highest IVSD was observed for fermented products. Boiled, malted and germinated sorghum had the lowest IVSD. All other products had digestibility values between these two extremes. The IVPD decreased significantly in most sorghum products, except in fermentation where IVPD was similar to untreated grain. Malted and germinated sorghum had IVPD significantly higher than all the other products and unprocessed grain. IVPD and TD was found to have a significant positive correlation.

In bioavailability studies it was noticed that most whole grain products gave higher NPU values, but dehulled products had higher digestibility values. Correlation coefficients indicated that NPU and TD did not have any significant correlation. NPU was positively correlated with DE and DMD. Weight gain was also more in most whole grain products except in popped and parched sorghum where weight gain was low. Biscuits and dosa prepared from dehulled grain failed to maintain growth in rats. All dehulled products had low NPU, though values were not significantly lower than the untreated dehulled grain except in case of dosa and biscuit prepared from dehulled grain where it was significantly lower.

When the sorghum products were ranked and the over all ranking was considered, it was noticed that roti, prepared from whole and dehulled grain, malted and germinated grain, and idli prepared from dehulled grain appeared to have good protein and energy availability. Dehulled boiled grain also ranked good when all the bioavailability parameters were considered. Biscuit, dosa, popped, parboiled and parched grain either showed fair or poor protein and energy availability.

LIST OF ABBREVIATIONS

BV	-	Biological value
DE	-	Digestible energy
DMD	-	Dry matter digestibility
IDRC	-	International Development Research Centre
ICRISAT		International Crops Research Institute for Semi Arid Tropics
IVPD	-	*In vitro* protein digestibility
IVSD	-	*In vitro* starch digestibility
LSD_{05}		Least significant difference at 5% level
NPR		Net protein ratio
NPU		Net protein utilization
PER		Protein efficiency ratio
PRL		Prairie Regional Laboratory
RNV		Relative nutritive value
SAT		Semi arid tropics
TD		True protein digestibility

CHAPTER I

INTRODUCTION

Cereals by and large have been the most important staple food of the world. Cereal production in the world has increased steadily during the last two decades and has more than kept up with population growth. But, there exists considerable distribution problems which consistently increase the gap between countries with surplus and those with deficit. About one third of the total increase in production is due to expanding acreage at the cost of other crops and two thirds due to improved cultivars and management practices (Key 1981).

Sorghum bicolor (L.) Moench is an important world cereal crop usually ranking fifth leading world cereal in terms of total grain production (Rooney et al 1980, FAO 1982, FAO 1984). Sorghum is one of the most versatile crops grown in the world. The ability to withstand both drought and wet conditions provide it with unique adaptability to cropping systems under erratic rainfall distribution and adverse soil conditions. Its ability to withstand drought is due to its capacity to make use of available water more economically. The extensive root system combined with the physiological characteristic enable it to utilize large portion of soil moisture than most crops. It is cultivated largely in the semi arid tropics (SAT) where the climate is characterised by high incidence of solar radiation, high temperature and very variable rainfall. The semi arid regions cover much of the African continent, in Asia it includes most of India, eastern Java, north eastern Burma and Thailand. It includes most of the northern quarters of Australia, nearly all of Central America, portions of north eastern Brazil, Paraguay and Bolivia. More than 600 million people are estimated to live in the SAT region with 56% of them in India (Swindale et al 1981).

In the Western hemisphere, sorghum has traditionally been used as livestock feed with 1-2% of total production being used for food and industrial products. In Africa and India nearly all sorghum grain is utilized directly as human food (Rooney et al 1980), and may provide up to 50% of the dietary protein (Cluskey et al 1979). Sorghum is also grown for various food and feed purposes and like sugarcane and maize, has potential as a raw material for energy production and chemical/industrial products manufacture (Careelman et al 1981). In Asia sorghum grain ranks third after rice and wheat as a cereal for human consumption and is second only to maize in Africa (Rachie 1969).

Sorghum is the major staple of a large segment of the populace living in the SATs. In India it is a popular staple food in Andhra Pradesh, Maharashtra, Karnataka and other parts of the country (Belavady 1977). Though the grain sorghum provides an important source of carbohydrate and is similar to other major cereals as a source of total protein, the protein quality is relatively poor in comparison with that from other major cereal grains (Axtell et al 1979). Over the years much work has been done by breeders, agronomists, entamologists and pathologists on the production of improved varieties and hybrids of sorghum. Most of this work has been successfully directed at maximizing and stabilising grain yields. While it may suffice to concentrate on quantitative aspects of sorghum production for animal feeds, quality aspects must be taken into consideration when the end product is to be used for human consumption (Kapasi-Kakama, 1977).

Basically sorghum contains just as high levels of the major nutrients-starch and protein, as the other cereals which are considered to be adequate for growth and maintenance when consumed in required quantities. However, in the case of sorghum three major factors complicate the full utilization of the starch and protein. First, protein and energy availability is limited in some sorghum genotypes by the presence of polyphenolic compounds (tannins) located primarily in the testa layer of the grain. Second, the protein quality of an all-sorghum diet is limited by the low lysine content of the grain. Third, there are specific dietary limitations in the utilization of cooked and baked sorghum products for humans due to factors such as high gelatinization temperature of starch and the high viscosity of the cooked products leading to problems with regard to acceptability and digestion (Axtell *et al* 1982).

Thus, many researchers all over the world who are concerned about the increased food uses of sorghum are engaged in the improvement of this cereal through breeding and processing programmes. Recent discoveries of high lysine sorghum lines (Singh and Axtell, 1973) have also encouraged breeding of a grain that can make a better contribution to protein quality requirements (Cluskey *et al* 1979). Breeding is a long term approach, whereas improved processing techniques and better utilization of existing varieties will be significant in the long and short term. The most efficient way of improving sorghum grain utilization will be, a combination of better processing techniques with better varieties of sorghum (Kapasi-Kakama 1977 and Rooney *et al* 1972).

The improvement of the grain quality of sorghum needs special attention because the people consuming sorghum are most often of the low socio-economic strata and live in dry land areas where the choice and chance of improving their diet with components other than the staple is extremely limited. Moreover, any significant effort to improve the utilization of sorghum which involves a radical alteration in the dietary habits of the population or the agricultural practices of the region would not be easily accepted.

It is customary to process any cereal grain before consumption. Processing may be just dehulling to remove the bran and/or reducing the grain to a flour (primary processing) or various other treatments like popping, parching, malting, fermenting, etc. (secondary processing) which will help to remove the raw flavour of the grain and produce the desired aroma or taste in addition to the altering of the texture of the product. Processing either primary or secondary may have some effect on the composition and nutritional quality of the grain due to loss or changes in the bioavailability of the nutrients.

The traditional processing methods for sorghum in all the countries involve time consuming hardwork (Vogel and Graham 1978). Sorghum is processed for food traditionally, in several ways depending upon the need and local habit. Dry milling into flour or grits is common, and in some cases whole grain is soaked and wet milled (Subramanian and Jambunathan 1980). The grain may also be dehulled depending upon the requirement. Dehulling in the traditional wet method may result in the loss of valuable nutrients and also increase the moisture content of the flour thus making it more prone to spoilage. Mechanical processing of sorghum will decrease the tedious hand processing time, moisture content and the amount of hull present in the resultant flour. No cheap and efficient technology is yet available for mechanical dehulling of sorghum grain but currently studies are being carried out in a number of research centres on mechanical dehulling of sorghum. A few dehullers have been designed and are being tried out on experimental basis, rice milling equipments and barley pearlers are also being adopted for pearling sorghum grains. A PRL dehuller developed by the Prairie Regional Laboratory appears to be a promising dehulling device. It is an extensively modified form of George Hill grain thrasher (Reichert 1982).

The International Symposium on Sorghum Grain Quality (1981) held at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) discussed the various aspects of grain quality. Grain quality can probably be considered to be made of two main parts (i) evident quality which is based on appearance, flavour and cooking quality characteristics and (ii) cryptic quality based on nutritional value (Jambunathan 1980). The first part, that is, the evident quality based on appearance, flavour and cooking quality characteristics of sorghum have been looked into in the past decade and in the Symposium on Sorghum Grain Quality held at ICRISAT (1981), a number of such studies have been discussed and reviewed. The second part of the grain quality, the nutritional quality especially of processed grain has not received sufficient attention.

There is very scanty information on how processing methods influence the nutritional quality of sorghum diets.

Studying the effect of processing on the nutritional quality of sorghum could result in the identification of the better processing methods. Identification of better method of processing will not only improve nutritional quality of the diet, but also help the women to save on their time and energy as a large number of housewives living in dry land areas have to spend half an hour to one hour daily for dehulling (Pushpamma and Chittemma Rao 1981). Even a marginal improvement in the nutritional quality of the sorghum based diet will go a long way to help in improving the overall nutritional status of people of the SATs.

The present study was therefore taken up with the objective of studying the composition and availability of the nutrients from whole and dehulled sorghum by traditional and mechanical dehulling. Sorghum grain products which are regularly consumed and also the products standardised in the food and nutrition laboratory of the College of Home Science, A.P. Agricultural University, Hyderabad, using different primary and secondary processing techniques were also assayed for the availability of nutrients using both *in vitro* and bioassay methods.

CHAPTER II

REVIEW OF LITERATURE

Sorghum kernels are generally spherical and have a thousand kernel weight ranging from 20-30 g. Kernel colour may be white, red, yellow, or brown (Hoseney *et al* 1980). The structure of the sorghum kernel plays a major role in determining the processing properties of the grain, and is affected by the genotype and environmental conditions (Rooney and Miller 1981).

2.1 MORPHOLOGY OF SORGHUM GRAIN

The structure of sorghum has been reported in detail by several workers (Sanders 1955, Rooney and Clark 1968, Rooney 1973, Hoseney *et al* 1974, Rooney and Sullins, 1977, Rooney and Miller 1981 and Zeleznak and Varriani-Marston, 1982), and is briefly stated in the following pages.

The sorghum caryopsis is composed of three main components. (1) The seed coat consisting of pericarp and testa together forming the outer covering (2) the embryo or germ and (3) the endosperm-storage tissue (Hulse *et al* 1980).

2.1.1 The Seed Coat

Seed coat consists of fused (a) pericarp and (b) testa.

.1.1.1 *Pericarp*. The extreme outer layer is the pericarp and is composed of three or four different layers (i) the outer most is the epicarp (ii) the hypoderm which may or may not always be differentiated from the epicarp (iii) the mesocarp - the middle layer and (iv) the endocarp (Hoseney *et al* 1980 and Hulse *et al* 1980).

The epicarp may or may not be pigmented and this feature is genetically controlled (Hulse *et al* 1980). The mesocarp is generally the thickest layer of the pericarp but can vary significantly among genotypes. Mesocarp cells contain polygonal starch cells. The endocarp consists of cross and tube cells.

.1.1.2 *Testa*. The layer immediately below endocarp and surrounding the endosperm is the testa and this part of the seed is subject to the greatest controversy. The presence or absence of testa appears to be genetically controlled (Hulse *et al* 1980). The testa may or may not be pigmented and this feature also appears to be genetically controlled. The pigmentation of both pericarp and testa is generally attributed to the presence of polyphenols (tannins) (Hulse *et al* 1980).

2.1.2 Embryo

The embryo consists of a large scutellum, an embryonic axis, a plumule and a primary root. The scutellum is the flattened portion that serves as an absorptive organ. There is a cementing layer between the scutellum into the endosperm. The embryo is relatively firmly embedded and is difficult to remove by dry milling (Rooney 1973).

2.1.3 Endosperm

The endosperm represents the largest proportion of the kernel and consists of an aleurone layer which is a single continuous layer of cells around the extreme edge of the endosperm peripheral, corneous and floury zones.

The peripheral layer is made up of cells containing a high proportion of protein. The corneous layer, beneath the peripheral layer, contains less protein and a higher proportion of starch than the peripheral. The corneous endosperm is also termed as the flinty, hard, or horny endosperm, and is translucent in appearance. Inside the corneous layer is found the floury or soft endosperm layer, which is lowest in protein (Hoseney et al 1980 and Hulse et al 1980).

2.2 STRUCTURAL COMPOSITION

Hubbard et al (1950) described the composition of the components parts of the hand dissected sorghum kernel. The whole grain was separated into bran, germ and endosperm. The proportion of endosperm ranged from 81.1 to 84.6%, the germ from 7.8 to 12.1% and bran from 7.3 to 9.3%. They have also reported the composition of the component parts of the sorghum.

Haikerwal and Mathieson (1971) have also reported the components of sorghum grain after hand dissection. The pericarp was 5.4%, germ 8% and endosperm 86.5% of the entire kernel.

Rooney _et al_ (1980) have reported that sorghum kernel is composed of 80-82% starchy endosperm, 6-8% bran (pericarp and associated layers) and 10-12% germ. Sorghums with a thin pericarp without a testa and with a small germ can contain as high as 86% or more of endosperm.

2.3 PROXIMATE COMPOSITION

The proximate composition of sorghum as reported by several workers is listed in Table 1.

Table 1: Proximate composition of sorghum grain

	References			
	Bressani and Rios (1962)	Bredon (1961)*	Aucamp (1961)	Lamar et al* (1972)
Number of samples	25	31	8	5
Protein %				
Mean	10.9	10.1	10.7	13.6
Range	8.8-14.5	8.1-13.7	8.5-11.9	11.8-16.6
Ether Extract %				
Mean	3.9	2.8	3.6	2.8
Range	3.6-5.2	1.8-5.2	1.6-4.6	2.5-3.4
Crude Fibre %				
Mean	3.0	2.5	4.7	-
Range	2.3-3.5	1.4-4.9	3.4-7.3	-
Ash %				
Mean	3.0	2.6	1.7	1.6
Range	1.6-4.5			
Carbohydrate %				
Mean	-	71.8 (Starch)	-	71.5
Range	68.4-74.5	-	67.0-75.0	-

*Cited in Rooney et al (1980)

contd.

Table 1. contd.

	References			
	Rooney (1973)	Mali and Gupta (1974)	Sisodia and Gupta (1979)	Neucere and Sumrell (1980)
Number of samples	234	16	15	5
Protein %				
Mean	11.0	13.6	8.2	11.5
Range		11.5-16.9	7.3-8.9	9.4-14.3
Ether Extract %				
Mean	3.4	3.4	-	3.1
Range	2.0-5.3	2.7-4.4	-	2.7-3.5
Crude Fibre %				
Mean	2.4	1.2	-	2.1
Range		1.1-1.5	-	1.4-2.6
Ash %				
Mean	1.8	1.9	-	1.6
Range				
Carbohydrate %				
Mean	81.0	69.9 (Soluble carbohydrate)	58.0 (Starch)	69.1 (Starch)
Range		66.2-72.4	57.0-61.5	65.0-72.1

contd.

Table 1. contd.

	References	
	Thakre (1981)	Jambunathan *et al* (1984)
Number of samples	12	100
Protein %		
Mean	9.6	11.4**
Range	8.3-11.2	4.4-21.2
Ether Extract %		
Mean	2.3	3.3
Range	1.8-2.6	2.1-7.6
Crude Fibre %		
Mean	-	1.9
Range	-	1.0-3.4
Ash %		
Mean	1.8	2.1
Range		
Carbohydrate %		
Mean	66.8 (Starch)	70.8 (Starch)
Range	64.4-72.1	55.6-75.2

**mean at 34,389 samples

Sorghum composition varies significantly due to genotype and environment. The variability is probably due to the fact that sorghum is produced under more variable conditions than most other cereals. Generally, grain yield is inversely related to protein content of sorghum. Fibre and ash composition are similar to other cereals with a marked caryopsis (Rooney et al 1980).

2.3.1 Carbohydrates

Starch, cellulose, simple sugars and pentosans comprise approximately 80% of the dry weight of the kernel with starch usually 70-75%. Sorghum starch contains 20-30% amylose and 70-80% amylopectin. The gelatinisation temperature range of sorghum starch is 67-77^{o}C (Rooney et al 1980). Glucose, fructose, sucrose, and traces of raffinose and stachyose are found in sorghum. Total soluble sugars range from 1.30-5.19% (Subramanian et al 1980), though higher value for sugary varieties have been reported (Karper and Quinby 1963). The pentosan content of sorghum ranges from 2.6-5.2% of the dry grain and is located mainly in the pericarp and germ (Karim and Rooney 1972a, 1972b, and Rooney et al 1980).

2.3.2 Lipids

Sorghum oil is concentrated in the germ, pericarp and aleurone layer at a level of 3.5%. The germ contains more than 79% of the total oil. The fatty acid composition consists primarily of linoleic, oleic, palmitic, stearic, and linolenic acids. The free lipid fraction extracted with petroleum ether consists of hydrocarbons tri-, di- and monoglycerides, free fatty acids and some polar lipids. (Rooney et al 1980).

2.3.3 Amino Acid Composition and Protein Fractions

Lysine is the first limiting amino acid, followed by methionine and cystine and threonine. (Virupaksha and Sastry 1968, Skoch et al 1970, Austin et al 1972, Mali and Gupta 1974, Salunkhe et al 1977, Rooney et al 1980). The amino acid composition as reported by several authors is given in Table 2.

Table 2: Essential amino acid composition of sorghum grain (g/100 g Protein)

	References			
	Bressani and Rios (1962)	Deyoe and Shellenberger (1965)	Virupaksha and Sastry (1968)	Shoup *et al* (1970)
Number of samples	25	30	9	7
Protein %	-	10.4	14.5	10.3
Lysine	2.9	2.0	2.1	2.3
Leucine	14.3	13.1	16.5	13.8
Phenylalanine	4.3	4.8	5.4	5.3
Valine	6.0	4.9	5.4	5.0
Tryptophan	0.7	-	-	-
Methionine	1.6	2.3 (met and cys)	2.3 (met and cys)	3.8 (met and cys)
Threonine	3.8	3.1	3.3	3.5
Histidine	3.3	2.1	1.9	2.7
Isoleucine	4.7	3.8	4.7	4.1

contd.

Table 2. contd.

	References				
	Swaminathan *et al*(1970)	Deosthale *et al* (1972)	Lamar *et al** (1980)	Mali and Gupta (1974)	Antogiovanni *et al* (1980)
Number of samples	6	24	5	16	5
Protein %	11.2	9.4	13.6	-	-
Lysine	2.1	2.5	1.9	1.8	2.0
Leucine	13.2	15.6	13.1	13.4	13.1
Phenylalanine	4.7	-	4.8	-	5.0
Valine	6.0	-	4.6	-	4.4
Tryptophan	0.9	1.0	-	0.9	1.8
Methionine	1.7	2.2	1.5	1.7 (met and cys)	2.9 (met and cys
Threonine	2.1	-	2.9	2.5	3.2
Histidine	2.1	-	2.0	-	1.9
Isoleucine	4.4	5.4	3.6	-	3.2

*cited in Rooney *et al* (1980).

Sorghum proteins are difficult to extract. The albumins and globulins, located primarily in the germ, aleurone layer and pericarp have the highest level of lysine and other essential amino acids. Kafirin (prolamin fractions) is high in glutamic acid and the nonpolar amino acids, it is low in lysine and methionine. The kafirin fraction is positively correlated with sorghum protein content (Virupaksha and Sastry 1968, Salunkhe et al 1977, Rooney et al 1980). Therefore increase in protein content due to fertilizer or other reasons only dilutes the percent of essential amino acids present. The kafirin proteins are located in the endosperm in spherical protein matrix. The glutelins are insoluble in neutral solvents and are major constituents of the matrix proteins in the sorghum endosperm (Well and Blessin 1969, Rooney et al 1980). The fractions of sorghum protein as reported by several authors are tabulated in Table 3 and 4

Table 3: Protein fraction (%) of sorghum grain by Osborne method

	References			
	Virupaksha and Sastry (1968)	Skoch *et al* (1970)	Haikerwal and Mathieson (1971)	Neucere and Sumrell (1979)
Number of samples				
Albumin				
Mean	5.7	3.8	20.0	23.4
Range	1.6-9.2	2.2-4.9		4.3-30.4
Globulin				
Mean	7.1	3.9	8.0	11.6
Range	1.9-10.3	2.5-5.8		1.0-17.9
Prolamin				
Mean	52.7	5.8	30.0	51.8
Range	39.3-72.9	3.9-8.5		40.6-60.3
Glutelin				
Mean	34.4	17.7	12.0	13.7
Range	23.5-45.0	14.9-20.8		4.5-34.3
Residue				
Mean		59.1	30.0	5.2
Range		52.8-62.6		3.6-7.0
Extraction efficiency	88.4		70.0	

Table 4: Protein fractions (%) of sorghum grain by Landry-Mouraux extraction procedure

	References			
	Jambunathan and Mertz (1972)		Walker* (1974)	Meckenstock* (1979)
	Whole grain	endosperm	Whole grain	Whole grain
Number of samples	4	4	3	21
Fraction I	10.5	5.1	17.1	17.5
Albumin and Globulin	(4.1-16.8)	(2.8-8.0)	(16.4-18.5)	(13.8.22.4)
Fraction II	9.4	14.0	5.9	8.0
Kafirin	(2.5-18.4)	(9.2-19.9)	(5.3-6.2)	(4.0-13.3)
Fraction III	15.6	30.0	19.9	20.5
Cross linked kafirin	(11.6-18.9)	(27.0-35.1)	(18.1-19.1)	(1.0-30.6)
Fraction IV	11.2	9.4	4.6	3.2
Glutelin like	(6.1-17.3)	(6.4-11.2)	(4.5-4.8)	(1.9-4.9)
Fraction V	42.0	32.8	32.3	31.1
Glutelin	(29.9-54.8)	(24.0-35.7)	(29.9-34.6)	(20.3-44.7)
Extraction efficiency	88.7	91.2	79.8	80.2

*cited in Rooney et al 1980

values in parenthesis indicate range.

2.4 BIOLOGICAL EVALUATION OF WHOLE SORGHUM

Most of the information on the biological value of sorghum has been obtained from animal rather than human subjects (Hoseney *et al* 1980).

Sorghum diets when fed to adult rats at 5% protein level gave a BV of 83% and digestibility coefficient of 91% (Swaminathan 1937a). But the PER of sorghum diet at 5% level of protein was reported to be 0.78 (Swaminathan 1937b). When sorghum protein was fed at 10% level the PER was found to be 1.61 (Phansalkar *et al* 1957). Kuppuswamy *et al* (1958) in a review of the nutritive value of certain cereals consumed in India reported the PER of sorghum to be 0.2-0.89 at 5-6% protein level and 1.4-1.8 at 9-11% level of protein. The BV of sorghum was reported to be 83%.

The effect of supplementing amino acid to sorghum diet of weanling male rats was studied by Pond *et al* (1958). The addition of 0.5% of L-lysine and 0.2% DL threonine to the sorghum diet was observed to produce growth approximately equal to that obtained with a purified diet containing 11% casein, but was inferior to that obtained with a 21% casein purified diet. The addition of 0.2 or 0.3% DL isoleucine, 0.95 or 0.1% DL-methionine, 0.1% of DL-tryptophan or 0.2% of

DL-valine had no effect on growth rate. Therefo was concluded that lysine and threonine were probably the most limiting amino acids in sorghum.

Waggle et al (1966) compared the nutritive value of 2 sorghum grain composites containing 7.9% and 11.8% protein respectively. Rat assay showed that the nutritive value as studied by weight gain of animals of the diet of low protein sorghum grain was superior to that of a high protein sorghum grain. Addition of lysine, histidine and arginine to high protein sorghum diet resulted in an increase in growth.

Nawar et al (1970) also reported that supplementing sorghum diet with lysine, threonine and methionine stimulated growth in rats. They studied the nutritive value of 10 lines of sorghum from world sorghum collection. Digestibility varied considerably between varieties, ranging from 48.9-88.1%.

The nutritive value of 10 varieties and 4 hybrids of sorghum grain was studied by rat experimentation by Breuer and Dohm (1972). Significant differences were observed in the nutritive value between varieties. Nutritive value was found to be negatively correlated with protein digestibility.

Pushpamma et al (1972) in a study determined the nutritive value of sorghum by amino acid analysis and by PER.

Sorghum was found to be deficient in three or more amino acids. The PER of sorghum was 1.4 and on supplementation with lysine it increased to 2.1. Lysine + tryptophan supplementation further improved PER to 2.5. Tryptophan without lysine was found to be ineffective, indicating that lysine was the most limiting amino acid.

Six varieties of sorghum were assayed using rats to determine their digestible and metabolizable energy contents by May and Nelson (1974). The varieties differed in tannin content and amino acid composition. Variable digestible and metabolizable energy values were obtained for different varieties. The tannin contents of the varieties did not influence the energy utilization by rats.

Herbers and Davis (1974) used scanning electron microscopy technique to observe starch granule and endosperm cell wall digestion in the gastro-intestinal tracts of rats. Minute starch granule damage occurred in sample recovered from the rat stomach. Hydrolysis of exposed starch granules was prominent in split kernels recovered from the jejunum. Several layers of endosperm cell walls were broken as the kernels passed through small intestine, however, cell walls diminished amylolysis of underlying starch granules. Amylolytic patterns in the samples from small intestine were analogous with those from the cecum and large intestine and feces. Breaks in the endosperm wall appeared to increase during digestion in the cecum and large intestine. Most of the pericarp was observed to have escaped hydrolysis.

Differences in the response of rats to sorghum diets were observed by Ilori and Conard (1976) while evaluating several lines. They felt that the difference probably was due to the variation in the amino acid composition rather than the dry matter digestibility or crude protein digestibility.

Harden et al (1976) compared the protein in sorghum with that of corn, with the dietary protein at 8% level, using rats as experimental animals. The nutritive values of both the grains were found to be similar.

Influence of polyethylene glycol on the digestibility of proteins in high tannin sorghum in rats was reported by Ford and Hewitt (1977). Digestibility, BV and NPU of whole sorghum grain was found to be 53%, 77% and 42% respectively.

PER and NPR of different varieties of sorghum was evaluated by Sikka and Johari (1979) and it was found that the protein quality of CSH-1 was the best followed by CSH-2 and Swarna. They also found that fortification of sorghum grain with lysine at 9% level increased the PER and NPR values significantly.

Khalil et al (1984) investigated two sorghum cultivars for their chemical composition and nutritional quality. The two cultivars, white and reddish white were similar in proximate composition, in vitro protein digestibility and calculated PER.

2.5 DEHULLING OF SORGHUM

Dehulling of sorghum can broadly be classified into three sections.

1) Traditional dehulling which is done in villages at the household level.

2) Adopted milling technology borrowed from wheat, maize and rice milling and

3) Methods specially designed for sorghum dehulling.

The proximate composition of whole and dehulled sorghum as reported by several authors is tabulated in table 5.

Table 5: Proximate composition of whole and dehulled sorghum grain

	Extraction Rates %	Protein	Fat	Ash	Fibre	Reference
Whole	100	12.0	2.6		3.1	Raghavender Rao (1964)
Dehulled a	95.5	12.0	2.2	1.5	2.0	
b	92.2	11.5	1.9	1.4	1.7	
c	88.0	11.4	1.3	1.3	1.1	
Whole	100	9.6	3.4	1.5	2.2	Hahn (1969)
Dehulled a	93.6	9.4	3.0	1.2	1.3	
b	88.8	9.4	2.5	1.1	1.0	
c	83.9	9.1	1.0	0.9	0.8	
Whole	100	11.3	4.2	1.7	1.8	Viraktamath *et al* (1971)
Dehulled a	96.3	11.0	3.8	1.5	1.0	
b	93.0	10.7	3.2	1.3	0.8	
c	90.5	10.5	2.2	1.1	0.7	
Whole	100	10.85	3.3			
Dehulled a	85.8	10.15	1.8			
b	80.8	10.16	1.6			James (1982)
Whole	100	14.4	3.1	1.4		
Dehulled	86.5	14.1	2.7	1.3		
Whole	100	15.6	4.2	2.0	2.2	Pedersen and Eggum (1983)
Dehulled a	95	15.8	4.0	1.8	1.8	
b	90	16.0	3.5	1.6	1.8	
c	80	16.3	2.7	1.2	1.6	

Since 1972, the International Development Research Centre (IDRC) has supported several research projects whose purpose was the development of systems by which to produce acceptable flour and other milled products from the major cereal and grain legume crops of the SAT. The Prairie Regional Laboratory (PRL) of National Research Council of Canada in Saskatoon has been much involved in the related engineering research and development of suitable dehullers.

The traditional dehulling practices followed in various countries have been discussed at length by Vogel and Graham (1979) and Hulse et al (1980) The traditional dehulling methods practical in India have been documented by Pushpamma and Chittemma Rao (1981) and Subramanian and Jambunathan (1980). Hulse et al (1980) have also reviewed the various mechanical methods of dehulling sorghum grain which include abrasion and attrition types of dehulling. Riechert (1982) reviewed the various mechanical dehulling devices available for sorghum. Both attrition and abrasive types of dehullers were discussed. Abrasive type of dehulling was found to be better than attrition type of dehulling (Riechert and Youngs 1976). Among the abrasive type of dehullers Oomah et al (1981) showed that PRL dehuller equipped with resinoid discs and the PRL/RICC dehuller equipped with fine grit stones were more efficient than HGT equipped with coarse-grit carborundum stones. He reported that to produce the same acceptable colour (Agtron spectrophotometer), the yield was 12 to 15% lower with GHT than with PRL or PRL/RICC dehuller.

The PRL mini dehuller was one of the several dehulling devices discussed by Riechert (1982). It operates on a maximum load of 7-kg batch and is useful in a laboratory situation or in a village setting where it can perform service function. In this dehuller carborundum stones or resinoid discs provide the abrasive action. Riechert (1982) pointed out the need of comparative studies to optimize the abrasive surface in dehulling to permit the most selective removal of hull layers and to maximize the yield of the edible product.

2.5.1 Traditional versus Mechanical Dehulling

Favier *et al* (1972) reported that there was a greater loss of material from the traditional pestle and mortar method than in mechanical dehulling as grain was thrown out of the motar during pounding. They have reported the following chemical composition for traditionally and mechanically dehulled sorghum grain.

Table 6: Chemical composition of traditionally and mechanically dehulled sorghum grain

	Traditional dehulling	Mechanical dehulling	Whole
Protein %	9.5	8.5	9.6
Fat%	1.4	1.3	3.0
Total Carohydrate %	88.0	89.3	85.6
Ash %	1.0	0.9	1.8
Calories	411	412	383

John and Muller (1973) reported the effect of milling sorghum to varying extraction rates by the traditional mortar and pestle method followed by grinding and by roller milling. The results show that the nutrient content decreased with decreasing extraction rate and that the nutrient loss was greater in the mechanical milling than the traditional method. Roller-milling removed more germ and bran than the traditional process. The composition of the traditional and mechanically dehulled grains was reported as follows.

Table 7: Chemical composition of roller milled and pestle and mortar milled sorghum

	Extraction rate (%)	Protein (%)	Fat (%)	Fibre (%)	Ash (%)
Roller-milled	100	8.2	2.6	1.3	1.3
	90	6.0	1.3	0.8	0.2
	70	3.5	0.3	0.8	0.5
	50	2.0	0.3	0.3	0.5
Pestle and mortar-milled	100	8.2	2.6	1.3	1.3
	90	7.3	2.2	1.1	1.1
	70	5.5	1.7	0.9	0.9
	50	3.4	1.2	0.6	0.5

Riechert and Youngs (1977) have compared mechanically (abrasive and attrition type) and traditionally dehulled sorghum for protein, ash, oil and crude fibre content. Mechanically dehulled grains contained 31-51% less oil and ash and 9-18% less protein at 75% extraction than whole grains. Traditionally dehulled grains contained 7-21% less oil and ash and 5-9% less protein at 75% extraction than whole grains. They also found that abrasive type of dehuller was more efficient in removing crude fibre than the attrition type of dehulling or the traditional method.

2.6 ANIMAL STUDIES USING WHOLE AND DEHULLED SORGHUM

Rao <u>et al</u> (1958) studied the nutritive value of whole and dehulled sorghum by bioassay. They found that a poor vegetarian diet based on whole sorghum diets promoted significantly higher growth in rats than in a similar diet based on dehulled sorghum diet. Rats fed on whole sorghum diet also retained significantly larger amounts of nitrogen than those on dehulled sorghum however, the digestibility of dehulled grain was higher (77%) than the whole grain (71.2%).

Eggum <u>et al</u> (1982) in a study reported the TD, BV, NPU and DE of whole and decorticated sorghum. Rats fed whole sorghum diets had higher weight, and BV and NPU was also higher when compared to rat fed decorticated grain, Protein TD and DE however was higher in the decorticated diet when compared to whole grain diet.

Pedersen and Eggum (1983) studied the nutritive value of dehulled low tannin sorghum flour with extraction rates between 100 and 64%. It was observed that the content of essential nutrients decreased when the extraction rate was lowered, but the content of fibre, tannins and phytates was also significantly reduced by milling. The digestibility of energy and protein was high, but the protein quality was poor, especially in flours of low extraction. Amino acid supplementation improved protein utilization and weight gain considerably.

2.7 EFFECT OF PROCESSING

2.7.1 Parching

Acharya et al (1942) examined the effect of parching on the BV of sorghum. Using market sample the following steps were followed for processing the grain.

(a) Sprinkled with water or saline solution

(b) Mixed with about 4 x its own volume of preheated (235-240^{o}C) sand in a frying pan over an open fire.

(c) Parched by rapid mixing in the frying pan with a ladle; the temperature of the grain rose to about 132-136^{o}C in 2-3 minutes and

(d) Separated from sand by sieving.

Rat feeding trials showed that parching raised significantly the BV of sorghum but increase in BV was not accompanied by an increase in digestibility.

2.7.2 Popping

Reeve and Walker (1969) popped sorghum grain under laboratory conditions by exposing to a temperature of 246^{o}C. Samples of raw and popped grain were examined microscopically under normal and polarized light. Observations showed that localized rupture of the cell wall occurred in the expanded endosperm. The spongy expanded endosperm consisted of intact cells within which the gelatinized starch formed a characteristic 'soap bubble' structure typical of popped grain. Endosperm cell walls near the aleurone layer remained mainly intact though some swelling was evident. Near the scutellum the endosperm starch granules remained ungelatinized. The scutellum did not expand and popping did not disorganise the structure of the embryo.

2.7.3 Boiling

FAO (1970) reported a personal communication from Dreyer (1963) that sorghum cooked and dried at 50°C fed to rats at 10% protein level gave a BV of 73.2%, digestibility of 76.3% and a NPU (calculated) of 55.8%.

The protein quality and digestibility of two high lysine (2.9-3.0g/100 g protein) and two conventional varieties (lysine content 2.1-2.2g/100 g protein) of whole grain sorghum milled as flour were assessed through balance studies in 13 children, 6-30 months of age by MacLean et al (1981). Sorghum proteins provided 6.4 or 8% of dietary energy. It was observed that sorghum consumption was associated with weight loss or poor weight gain. The mean nitrogen absorption of sorghum was 46% ($\pm$17) and retention was 14% ($\pm$10) of the intake.

Axtell *et al* (1981) reported an *in vitro* system which was sensitive to the digestibility differences between sorghum and other cereals, as weanling rats gave a digestibility value of 80% for cooked sorghum gruel and 85% for uncooked sorghum and human studies gave contradicting results (MacLean *et al* 1981). Porcine pepsin used in *in vitro* study showed digestibility differences. It was observed that with porcine pepsin, uncooked sorghum proteins gave a high digestibility (78-100%), which dropped to a range of 45-55% after cooking. The authors felt that digestibility values obtained from porcine pepsin assay could be extrapolated for children.

Ugali, a Tanzanian food product prepared by cooking sorghum flour in water was evaluated for its biological value by rat feeding trials (Eggum *et al* 1982). Whole and hand decorticated grains were used for the study. The authors expressed that whole grains *ugali* was more nutritious as the weight gain was 1.40g/day as compared to the decorticated grain *ugali* when the weight gain was 0.04g/day. This was probably due to the decrease in the lysine content on decortication. The lysine content of whole grain was 2.0 g/16g N and in the decorticated grain it was 1.2g/16g N. The TD BV, NPU and DE of whole and decorticated grain ugali were as tabulated below.

Table 8: Nutritional quality of *ugali* prepared from whole and dehulled sorghum by rat feeding trials

Diet	n	TD	BV	NPU	DE
Whole grain ugali		90.0	55.7	50.2	88.8
Decorticated grain ugali		91.8	49.4	45.3	94.0

2.7.4 Unleavened bread

Bressani *et al* (1977) compared white sorghum and maize in making of *tortillas* using the same process for both grains. It was found that sorghum *tortillas* were cooked in about half the time taken by maize. When the *tortillas* were fed to rats the protein efficiency ratio of sorghum *tortillas* was found to be 0.6 (protein level of diet 8.5%) and maize *tortillas* had PER of 1.0 (protein level of diet 9.3%).

The proximate composition of *roti* (unleavened bread consumed in India) has been reported by Pushpamma and Geervani (1981) and is tabulated in table 9.

Table 9: Proximate composition of sorghum *roti* per 100 g

Calorie	292
Protein (g)	8.0
Fat (g)	1.2
Carbohydrate (g)	61.8
Ash (g)	2.3
Fibre (g)	2.9

2.7.5 Baking

Sorghum flour does not contain any gluten in its protein. Therefore acceptable leavened products are difficult to prepare with 100% sorghum flour. Several studies have been reported where in bakery product, 5-30% of either whole or dehulled sorghum flour has been incorporated with wheat flour successfully (Futrell and Abdullahi 1967, Bhatia *et al* 1968, Dendy *et al* 1971, Rao and Shurpalekar 1976, Perten 1977, Rooney *et al* 1980).

A few studies have been reported where only sorghum flour has been used for bakery product. Badi *et al* (1978) have reported that acceptable biscuits, cakes, waffles and pancakes have been produced from 100% sorghum flour.

Khalil *et al* (1984) in a study using two cultivars of sorghum, white and reddish white found that baking had no effect on proximate and amino acid composition. The levels of lysine methionine and cystine and threonine in unleavened and leavened bread were as follows.

Table 10: Levels of lysine, methionine and cystine and threonine in unleavened and leavened bread

	Flour		Bread		
Amino acid	White	Reddish-white	White	Reddish white unleavened	Reddish white leavened
Lysine	2.5	2.6	2.4	2.6	2.9
Methionine and Cystine	2.6	2.5	2.8	3.0	3.3
Threonine	3.2	3.2	3.2	3.2	3.2

2.7.6 Fermentation

The nutrient content and the amino acid pattern of *kisra*, a fermented Sudanese bread was studied by El Tinay *et al* (1979) using three sorghum varieties. The results indicated that there was a slight increase in the protein content as a result of *kisra* fermentation and an appreciable drop in starch. Total and non-reducing sugars decreased markedly at the commencement of the fermentation process, while crude fibre content increased. Threonine and lysine remained practically unchanged during *kisra* fermentation. Tyrosine and methionine were enriched as a result of fermentation for all three varieties.

The nutrient composition of *ogi* (Nigerian food product) was reported by Hesseltine (1979) and is given in the table below.

Table 11: Proximate composition of sorghum *ogi* as %, on dry weight basis (except moisture).

	Sorghum	Sorghum *ogi*
Moisture	11.8	41.0
Crude Protein	11.3	11.3
Fat	3.9	2.7
Crude Fibre	1.5	1.6
Carbohydrate (by difference)	82.0	84.0
Ash	1.7	0.5
Calories	407	405

Au and Fields (1981) studied the relative nutritive value (RNV) of sorghum fermented at 25° and 35°C. The RNV of sorghum fermented at 25°C and 35°C increased significantly ($P<0.05$) over the % RNV of the control. During the consecutive 7 days fermentation at 25°C, time was found to have no effect on the % RNV. The highest RNV was achieved at the end of one day. Fermentation at 35°C was influenced by the time, with highest % RNV at the end of 7 days. Available lysine and methionine increased substantially ($P<0.01$) over the control when sorghum was fermented at 25°C or 35°C for 4 days.

Kazanas and Fields (1981) also reported a significant ($P<0.001$) increase in RNV as a result of fermentation in sorghum. Significant ($P<0.001$) increase was also reported in the lysine, leucine/isoleucine and methionine content. Authors report that although the fermentation produced increased availability of nutrients, it did not produce any change in the proximate analysis.

The proximate composition of *injera*, a leavened Ethiopian traditional bread prepared from dehulled sorghum was reported by Gebrekidan and Gelbrehewot (1982). The composition (Ethiopian Nutrition Institute 1980) is given in the following table.

Table 12: Proximate Composition of *injera* per 100 g

Calories	193
Moisture %	52
Protein (g)	7.1
Fat (g)	0.6
Carbohydrate (g)	39.8
Fibre (g)	0.9
Ash (g)	0.5

Eggum *et al* (1983) studied the nutritional quality of some fermented Sudanese food by rat feeding trials using three varieties of sorghum. Among the food products studied two food products were *kisra* and *aceda*.

The nutritional quality of *kisra* showed only minor differences compared to the uncooked materials. There was no change in DE, and the mean TD of the unprocessed diets was 96.8 compared to 94.2 for the three *kisra* diets. The NPU of whole *kisra* prepared from two sorghum varieties (Tetron and Feterita) were 48.9 and 47.3 respectively, NPU and *kisra* prepared from dehulled grain (Dabar) was 53.4. Uncooked fermented *aceda* had a slightly higher DE compared to cooked, unfermented acid adjusted *aceda*. The cooked *aceda* diets showed a decrease in TD. Only minor changes in lysine content was observed. The NPU of uncooked *aceda* were 45.9 whereas cooked *aceda* had NPU of 50.1.

2.7.7 Germination

Wang and Fields (1978) germinated sorghum seeds at 25°, 30° and 35°C and found that germination increased the relative nutritive value (RNV) and also increased levels of lysine, methionine and tryptophan when compared to non germinated seeds. The RNV of ungerminated sorghum was 55.5% whereas on germination it increased to 63.9%. The highest RNV was attained when the seeds were germinated for 5 days at 25°C, 6 days at 30°C and 3 days at 35°C. The highest RNV for sorghum was 78.3%.

The effect of germination on normal and high lysine sorghum was studied by Wu and Wall (1980). Both normal and high lysine sorghum were germinated for 10 days. Lysine content of germinated normal sorghum increased after 10 days from 2.2 to 3.2g/16gN. For sprouted high lysine sorghum, lysine content increased from 3.0 to 7.8g/16gN after 7 days. A large increase in albumin (rich in lysine) accompanied sprouting. The percent protein in germinated sorghum was found to be greater than in the initial grain as a result of dry matter loss in the grain during germination, but the absolute amount of protein per kernel did not increase.

Changes in tannin, starch, reducing sugars and free amino acids, during germination of low and high tannin sorghum were determined by Chavan et al (1981). About 73% and 20% tannin were lost during 120 hours germination in high tannin and low tannin seeds respectively. Accumulation of reducing sugars, free amino acids and degradation of starch were reported to be considerably low in high tannin seeds as compared to low tannin seeds. It was suggested that probably tannins were responsible for retarding seedling growth by decreasing the rate of starch and protein degradation in germinating high tannin seeds.

Endosperm modification in germinating sorghum grain was studied with scanning electron microscopy by Glennie et al (1983). Bird resistant sorghum grain was germinated at 28^{o}C for 12 days and samples were taken every day for microscopic examination. Endosperm modification began at the endosperm scutellum interface and subsequently moved into the floury endosperm, with slight modification of the peripheral endosperm. The horny endosperm was modified last. The matrix protein began to disappear first and after it was disrupted, the starch granules and protein bodies were degraded simultaneously. The aleurone cells did not appear to be active in enzyme production, the scutellum fulfilled this role. However, the aleurone cells were extensively modified during germination and their mineral content was greatly reduced.

The cell walls were the only part of the endosperm that appeared visually unchanged after germination. They retained their structure even after the endosperm was extensively modified and the cells had lost their contents.

Aisien and Palmer (1983) studied the time-course changes in the structural and physiological properties of sorghum grain embryo in relation to the hydrolysis of the endosperm during germination and seedling growth. Histochemical analysis showed that the reserve food material of the scutellum tissue were mobilized rapidly during germination. Electron microscopy studies showed that extensive metabolism of subcellular storage material occurred during germination. Dissection of sorghum showed that the whole body of the scutellum was capable of producing α-amylase.

2.7.8 Malting

In several African countries sorghum is fermented into beer and malting of the grain is a primary step in the brewing industry. Studies therefore have been directed towards varieties that produce desirable quantities and quality of α-and β-amylases-enzymes necessary in malt formation and also responsible for the diastatic power of malt (Novellie 1959, Novellie 1960, Novellie 1962a, and Novellie 1962b).

Von Holdt and Brand (1960) studied changes in carbohydrate of sorghum during malting. Sugars present in the grain were glucose, fructose and sucrose whereas the malt had in addition maltose and lower maltose oligosaccharide. During malting, the starch content decreased by 43%. It was observed that germination of kaffir corn was accompanied by a steady increase of fructose and sucrose which was apparent from the first day and continued until the fifth day. Maltose, isomaltose, maltotriose and traces of higher maltose oligosaccharides appeared on the first day and increased sharply over the whole 7 days experimental period, as did glucose.

Aucamp et al (1961) determined protein, fat, fibre, ash, thiamine, riboflavin and niacin content in eight varieties of sorghum grain and malt. From one malt sample a breakfast food was prepared and its composition was studied. Protein, fat, fibre and ash content of sorghum grain, malt and the breakfast food is given below.

Table 13: Protein, fat, fibre and ash content of sorghum grain, malt and the breakfast food prepared therefrom

	Grain n = 8		Malt n = 8		Breakfast food n = 1
	Range	Mean	Range	Mean	
Protein %	8.5-11.0	10.7	10.0-12.2	11.0	9.5
Fat %	1.6-4.6	3.6	1.4-3.0	2.8	3.6
Fibre %	3.4-7.3	4.7	2.5-5.0	4.2	3.5
Ash %	1.4-2.2	1.7	1.3-2.0	1.6	3.0

The amino acid composition of one variety of sorghum grain and malt as reported by Horn and Schwartz (1961), is tabulated in Table 14.

Table 14: Amino acid composition of sorghum grain and malt

	Grain	Malt
Aspartic acid	7.33	9.31
Threonine	3.39	3.46
Serine	4.19	4.27
Glutamic acid	18.0	17.6
Proline	8.2	8.42
Glycine	3.29	3.10
Alanine	8.44	8.02
Valine	4.54	4.74
Methionine	2.05	1.33
Isoleucine	3.02	3.37
Leucine	11.5	10.8
Tyrosine	4.21	4.00
Phenylalanine	4.79	4.78
Lysine	2.47	2.81
Histidine	2.45	2.46
Arginine	5.01	5.00
Cystine/2	1.19	1.21
Tryptophan	1.81	1.08

Development of rootlets and acrospires during germination of sorghum lead to a loss in the yield of malt. Khan et al (1977) have reported that seeds steeped in 0.3% ammonia showed higher moisture absorption and prevented the formation of rootlets and acrospires and thus minimised the loss during malting. The proximate analysis of sorghum malt (in water and in ammonia) is shown in the following Table.

Table 15: Proximate analysis of sorghum grain and malt

Chemical composition %	Whole grain	Malted (water)	Malted (ammonia)
Moisture	10.1	6.1	6.8
Crude protein	11.3	9.4	9.5
Crude Fibre	1.6	1.9	1.6
Fat	2.1	3.2	3.3
Ash	1.4	1.8	1.6
Carbohydrate (by difference)	73.4	77.7	77.2
Starch	63.4	48.2	52.8
Reducing sugars	3.5	7.1	5.7

The authors feel that the decrease in the quantity of protein and starch but increase in reducing sugars in the malted sample indicate, the formation and development of the malt enzymes even in the ammonia treated samples. So the ammonia treatment had no effect on the formation of malt enzymes but prevented formation of rootlets and acrospires which minimized the dry matter loss and increased malt yield.

The effect of malting on the protein and free amino nitrogen composition was studied by Taylor (1983). It was reported that when sorghum was malted (7 days) much of the nitrogen in the kernel was transferred to the roots and shoots. Examination of Osborne protein fraction extracted from the kernel revealed that the prolamines were the major sources of the nitrogen transferred. Electrophoretic prolamin bands remained unchanged during malting. This indicated that prolamins are degraded directly to small peptides and amino acids. There was a general decline in the number of glutelin proteins whereas some albumin plus globulin proteins increased in quantity while others decreased. In the roots and shoots there was considerable increase in both protein nitrogen and non protein nitrogen as a result of translocation of the products of storage protein breakdown from the kernel. Increased levels of all essential amino acids in the malt was also observed.

CHAPTER III

MATERIALS AND METHODS

The study was designed to cover the following aspect:

a) Chemical composition, <u>in vitro</u> digestibility and bio-availability of whole, traditionally and mechanically dehulled sorghum grain.

b) Chemical composition and <u>in vitro</u> digestibility of products* prepared from whole and dehulled grain and

c) Bioavailability of protein and energy from the products prepared from whole and dehulled grain.

The methodology followed for the study is elucidated.

3.1 PROCUREMENT OF GRAIN

Sorghum M35-1 variety was procured in bulk from the Agricultural Research Station, Mohol, Sholapur, Maharashtra, India.

*The words 'treated' and 'product' are used to refer to samples obtained after secondary processing, as the use of the word 'processing' is misleading since it may mean primary or secondary processing.

3.2 PREPARATION OF THE SAMPLE

The grain was cleaned and sieved to remove small, shrivelled, broken grains and other debris. The grain sample was stored under refrigeration during the research period.

3.3 PROCESSING OF GRAIN

3.3.1 Traditional Dehulling

Sorghum was dehulled using the traditional moisture conditioning method followed in Andhra Pradesh (Pushpamma and Chittemma Rao 1981). The cleaned and sun-dried grain was conditioned with water (250 ml/kg) and pounded in a stone mortar with wooden pestle for 4 minutes. This was followed by winnowing to remove the husk. The dehulled grain was washed three or four times with water to remove all the husk and light particles. The grain was then sun-dried and stored in a deep freeze till the time of the experiment.

Flow chart of dehulling of sorghum by wet attrition method.

Drying

↓

Cleaning

↓

Moisture conditioning with water (210-265 ml/kg)

↓

Pounding with a mortar and pestle (4 minutes)

Rubbing and winnowing

↓

Washing three or four times with liberal quantities of water to remove all the husk and light particles

↓

Sun drying

3.3.2 Mechanical Dehulling

The PRL (Prairie Regional Laboratory) mini dehuller (details of the dehuller and use is given in Appendix I) was used for mechanical dehulling. Batches of 3 kgs of grain was dehulled at a time, for various time periods to standardize the time required for dehulling. Five minutes was found to be suitable as it removed most of the bran. The grain was winnowed to remove the bran and clean dehulled grain was stored in the deep freeze till it was required for the experiment.

3.3.3 Preparation of Various Products from Whole and Dehulled Sorghum Grain

Various products were prepared from whole and dehulled grain by subjecting it to further treatments like, parching, popping, malting, germinating, parboiling, boiling, baking, and fermenting. (The details of the treatments and recipies of the sorghum products are given in appendix II).

The various sorghum products used for the study is given in the Table 16.

Table 16: The various sorghum products used in the study

Grain products		Flour products	
whole	dehulled*	whole	dehulled*
Parched	Boiled	Roti	Roti
Popped		Dosa	Dosa
Parboiled		Idli	Idli
Malted		Biscuit	Biscuit
Germinated			
Boiled			

*Chemical and biological tests with mechanically and traditionally dehulled sorghum flour was carried out first. Since no significant difference was observed between the two, further products were prepared with mechanically dehulled grain and flour.

Whole, traditionally dehulled and mechanically dehulled grain were milled into a flour in a mechanized domestic grinder (Milcent domestic electric flour mill) to a uniform partical size (30 mesh British Standard Sieve). The treated grains were dried in a hot air oven at 50^{o}-55^{o}C for 48 hours and ground to a flour.

3.4 CHEMICAL ANALYSIS

Whole, dehulled and treated sorghum flour were subjected to the following chemical analysis.

1. Crude protein, fat, fibre, ash and moisture were estimated according to the standard AOAC procedures (AOAC 1975).

2. Total Starch. The starch was digested with glucoamylase (Sigma) and the amount of glucose produced was determined by phenol - sulphuric acid reaction (Dubois et al 1956).*

3. *In vitro* digestibility of protein was assessed by pepsin digestibility method (Axtell et al 1981).*

4. *In vitro* digestibility of starch was determined by α-amylase (Kon *et al* 1971).*

5. Amino acid composition was obtained with Beckman automatic amino acid analyser (model 119CL), using the method of Moore and Stein (1963).

*Detailed procedures are given in Appendix - III.

3.5 BIOLOGICAL STUDIES

The NPU, and digestibility of whole and processed sorghum was determined by rat feeding trials. The procedure of Miller described by Pellett and Young (1980) was followed.

3.5.1 Diet Composition

Processed and ground sorghum grain were used in the preparation of the diet. Eighteen experimental diets and one control (non-protein) diet were tested by rat feeding trials.

All the experimental diets were prepared at 8% protein level and were isocaloric with calorific value ranging from 3.9 Cal/g to 4.1 Cal/g. The composition of 100 g of diet was as follows: test sample flour weight calculated to give 8% protein, groundnut oil 10 g, 4 g mineral mixture and 1 g vitamin mixture (NIN 1983). Potato starch and sucrose were used to adjust the calorie value of the diet.

The non protein diet containing less than 0.1% nitrogen was prepared according to the composition suggested by Pellett and Young (1980).

3.5.2 Rat Feeding Trials

Experimental animals:	Rats
Age:	23 days
Sex:	Male + Female [equal number]
Strain:	Wistar

The experimental animals were procured from Indian Drugs and Pharmaceuticals Limited (IDPL) at 23 days of age and introduced into the experimental room. They were fed on stock diet for one week. At the end of one week the rats were divided into groups of four, each having two male and two females, and the range of the total weights of groups did not exceed 2g.

Each group of rats received one of the experimental diets and one groups was fed on a non-protein diet. Four rats were treated as a group and housed in a single cage with a mesh bottom. The cage was placed on a metal tray, and arrangements were made for fecal collection. All test diets were assayed in duplicate with a different set of rats at different times.

Food and water was given ad libitum. The dry powdered diet was dispensed from weighed jars and pressed into containers designed to minimize spillage. Feces were collected daily and stored in air tight containers in the deep freeze till the time of analysis.

At the end of 10 days animals were killed with chloroform and incisions were made into the skull, thoracic and body cavity and dried in a hot air oven at 105°C for 48 hours. Spilt food and left over food was weighed and dry food intake was calculated by weight loss of the food jar multiplied by the percent dry weight of the diet, minus the dried spilt and uneaten food.

3.5.3 Carcass, Fecal and Food Analysis

3.5.3.1 Preparation of the Sample. The dried carcass was ground in a domestic mincer and preserved for nitrogen determination. The dried fecal matter was ground to a fine powder and used for nitrogen and energy determination. Dried food samples were stored in closed containers for nitrogen and energy determination.

.5.3.2 Determination of Nitrogen in Carcass, Food and Fecal Matter. The nitrogen content of the carcass was determined by macro-digestion with 10 ml of concentrated sulphuric acid per gram of dry matter plus an extra 10 ml and 20 g of selenium oxide and potassium sulphate (catalytic mixture). After appropriate dilution, the ammonia was determined by Technicon auto analyzer. Food and fecal nitrogen was also determined similarly by Technicon auto analyzer.

3.5.3.3 Determination of Food and Fecel Energy. The calorific value of the food and fecal matter was determined by using an oxygen bomb calorimeter (Parr Instrument Co).

3.5.4 Calculation

NPU, TD, DE and DMD were calculated using the following formulae.

$$NPU = \frac{B-B_K + I_K}{\ } \times 100$$

$$TD \qquad I-(F-F_K) \times 100$$

$$DE \qquad I_E-F_E \times 100$$

$$DMD = \frac{ID_M-FD_M}{ID_M} \times 100$$

NOTE :

B	Body nitrogen of experimental group.
B_K	Body nitrogen of non-protein group
I	Nitrogen intake of experimental group
I_K	Nitrogen intake of non protein group
F	Fecal nitrogen of experimental group
F_K	Fecal nitrogen of nonprotein group
I_E	Energy intake of experimental group
ID_M	Dry matter intake of experimental group
	Fecal energy content
FD_M	Fecal dry matter content

3.6 STATISTICAL ANALYSIS

The data was subjected to one way analysis of variance. Least significant difference(LSD) was calculated from standard error of means. LSD was used to test differences between all the pairs of means. All parameters were tested for correlation (Snedecor and Cochran 1967).

CHAPTER IV

RESULTS

The results of this study have been presented in three sections.

1) Proximate and amino acid composition
2) *In vitro* digestibility studies and
3) Bioavailability studies.

4.1 PROXIMATE AND AMINO ACID COMPOSITION

The results of proximate analysis and amino acid composition of whole, dehulled sorghum and products prepared thereof are reported in this section.

The proximate composition of whole, traditionally dehulled and mechanically dehulled sorghum flour is given in Table 17.

Table 17: Proximate composition of whole and dehulled sorghum flour

	Whole	Traditionally Dehulled	Mechanically Dehulled	LSD_{05}
Yield (%)	100	87.2	90.4	
Protein (%)	11.1	10.8(9.4)	10.9(9.9)	0.31
Fat (%)	3.5	2.5(2.2)	2.9(2.6)	0.22
Ash (%)	1.3	0.9(0.8)	1.2(1.1)	0.12
Crude Fibre (%)	2.0	1.2(1.1)	1.0(0.9)	0.25
Starch (%)	80.4	84.4(73.6)	83.6(75.5)	2.87

LSD Least significant difference at 5% level.

Figures in paranthesis indicate proportion of the proximates in terms of the whole grain.

On dehulling, both traditionally and mechanically, the fat, ash, fibre content decreased significantly ($P<0.05$) when compared to whole grain. In addition, the decrease in fat and ash content in traditionally dehulled grain was more. The starch in traditionally and mechanically dehulled grain showed a significant increase when compared to whole grain.

The composition of traditionally dehulled and mechanically dehulled grain were similar except that in traditionally dehulled grain the ash and fat contents were significantly lower ($P<0.05$) when compared to mechanically dehulled grain.

The protein and starch contents were not affected significantly on dehulling, when values were expressed in terms of percent of yield. But when the starch and protein contents were expressed as percent of the whole grain, it was observed that there were differences between mechanically and traditionally dehulled grain. Both protein and starch levels were then significantly higher in the mechanically dehulled grain.

The proximate analysis of sorghum flour and the various products is given in Table 18.

Table 18: Proximate composition (%) of whole and dehulled sorghum and their products (on dry weight basis)

	Protein		Fat		Ash		Fibre		Starch	
	W	D	W	D	W	D	W	D	W	D
Flour	11.1	10.9	3.5	2.9	1.3	1.2	2.0	1.0	84.4	83.6
Parched	10.3	–	3.0	–	1.7	–	1.6	–	76.0	–
Popped	9.8	–	3.1	–	1.9	–	2.1	–	79.9	–
Malted	10.2	–	2.8	–	1.3	–	1.2	–	74.1	–
Germinated	11.3	–	1.8	–	0.8	–	1.8	–	76.1	–
Parboiled	10.0	–	2.5	–	1.2	–	1.4	–	76.2	–
Boiled	10.4	10.3	2.9	1.5	1.5	1.9	2.0	0.9	74.3	78.8
Roti	10.7	10.4	1.6	1.1	1.7	1.2	1.8	1.1	73.0	76.6
Biscuit	9.5	9.0	14.3	13.3	2.5	2.9	1.4	0.9	62.9	65.2
Dosa	10.4	10.1	6.7	5.0	2.6	2.5	1.6	1.1	66.8	69.2
Idli	10.5	10.2	3.0	2.0	2.0	2.5	1.6	1.0	67.6	73.9
LSD_{05}	0.31		0.22		0.12		0.25		2.87	

W – Whole; D – Mechanically dehulled

LSD_{05} – Least significant difference at 5%

Subjecting whole and dehulled grain to various treatments appeared to affect the proximate composition of the product. Protein decreased ($P<0.05$) in most cases except on germination where there was a slight increase but it was not significant. Fat content decreased in most cases (except biscuit and dosa where exogenous fat was used in preparation of the product). Fibre content of whole grain products decreased significantly on parching, malting, parboiling, baking (biscuit) and fermenting (dosa and idli), when compared to whole grain. The dehulled grain product did not show any significant change in fibre content when compared to the untreated dehulled grain. Dehulled grain products had significantly lower fibre levels when compared to whole grain products.

Starch content of whole grain products decreased significantly, when compared to whole grain, with fermented products having the lowest starch content. Dehulled products also had significantly ($P<0.05$) lower levels of starch when compared to untreated dehulled grain.

The starch content of dehulled grain products were significantly higher than whole grain products. However, the starch content was not significantly ($P>0.05$) higher in dosa and biscuits prepared from dehulled grain as compared to those prepared from whole grain Differences in starch content between treatments were also observed, fermented products and biscuits had the lowest values. Popped grain and roti prepared from whole grain also had significantly lower starch content.

Amino acid composition of whole and dehulled sorghum is given in Table 19.

Table 19: Amino acid composition (g/100 g protein) of whole, traditionally and mechanically dehulled sorghum grain

	Whole	Traditionally dehulled	Mechanically dehulled
Lysine	2.43	1.92	2.03
Histidine	2.59	1.89	2.38
Arginine	3.76	3.39	3.61
Aspartic acid	7.41	6.61	7.13
Threonine	3.07	2.94	2.99
Serine	4.22	4.24	4.22
Glutamic acid	19.89	21.35	20.35
Proline	8.36	9.53	8.82
Glycine	3.08	3.00	2.85
Alanine	8.90	9.57	9.01
Half cystine	1.44	1.45	1.31
Valine	4.67	4.92	4.54
Methionine	2.11	2.07	2.06
Isoleucine	4.15	4.23	4.10
Leucine	12.25	12.72	12.44
Tyrosine	4.45	4.57	4.46
Phenylalanine	5.23	5.40	5.29

The amino acid composition was not altered to a great extent, except lysine which on dehulling, decreased by 21% in traditionally dehulled and by 16.5% in mechanically dehulled samples when compared with the lysine level in whole grain sample. The difference between the lysine content in traditionally dehulled and mechanically dehulled grain was 5%. There was a 5% decrease in methionine and cystine value in the mechanically dehulled grain whereas the level in traditionally dehulled grain was not affected. Threonine values were not affected to a great extent.

Amino acid composition of sorghum products are given in Table 20.

Table 20: Amino acid composition of sorghum products. [g/100g Protein]

	Parched	Popped	Malted	Germinated	Parboiled	Boiled whole	Boiled dehulled
Lysine	2.33	1.75	2.01	2.16	2.46	2.32	1.81
Histidine	2.53	2.59	2.46	2.34	2.71	2.55	2.27
Arginine	4.11	3.68	3.47	3.37	3.86	3.86	3.31
Aspartic Acid	7.37	7.48	7.11	7.28	7.25	7.06	7.05
Threonine	3.25	3.33	3.18	3.34	3.11	3.43	3.21
Serine	4.32	4.45	4.29	4.74	4.49	4.34	4.69
Glutamic Acid	20.26	21.06	27.13	20.37	19.81	20.12	21.36
Proline	8.54	9.11	8.96	9.70	8.60	9.58	9.40
Glycine	3.50	3.35	3.07	2.74	3.04	3.06	2.77
Alanine	9.01	9.47	9.17	9.67	8.85	8.95	9.51
Half Cystine	1.48	1.45	1.45	1.67	1.48	1.45	1.52
Valine	5.18	5.21	4.89	5.41	5.10	4.71	4.67
Methionine	2.32	2.22	1.94	2.13	2.22	2.20	2.16
Isoleucine	4.26	4.49	4.45	4.67	4.44	4.12	4.33
Leucine	12.26	12.26	12.57	11.85	12.14	12.40	12.68
Tyrosine	4.56	4.58	4.59	4.60	4.67	4.36	4.64
Phenylalanine	5.46	5.62	5.42	5.87	5.47	5.24	5.53

Contd. on p 69a

	Roti whole	Roti dehulled	Biscuit whole	Biscuit dehulled	Dosa whole	Dosa dehulled	Idli whole	Idli dehulled
Lysine	1.97	1.79	1.49	1.27	1.82	1.28	1.97	1.78
Histidine	2.30	1.92	2.04	2.37	2.11	2.33	2.44	2.52
Arginine	3.53	3.32	3.05	3.18	3.30	2.75	3.58	3.51
Aspartic Acid	6.83	7.20	7.90	7.12	6.34	6.63	6.92	6.67
Threonine	3.11	2.90	3.50	3.02	2.50	2.70	3.01	3.12
Serine	4.20	4.52	4.80	3.50	3.14	3.45	4.21	4.45
Glutamic Acid	19.32	19.46	20.84	20.55	18.61	19.96	19.52	20.52
Proline	9.47	10.62	9.65	8.92	7.56	8.24	8.56	8.75
Glycine	2.99	2.68	2.99	2.84	2.66	2.81	3.03	3.00
Alanine	8.58	9.56	9.59	9.28	8.19	8.93	8.82	9.45
Half Cystine	1.78	1.41	1.23	1.09	0.89	1.15	1.06	1.38
Valine	4.68	4.95	5.04	4.52	4.13	4.70	4.56	4.60
Methionine	2.11	1.99	2.20	2.09	1.81	2.01	2.04	2.12
Isoleucine	3.88	4.18	4.09	4.17	3.82	3.99	4.11	4.26
Leucine	12.03	13.12	11.58	12.39	11.30	11.45	12.10	12.51
Tyrosine	4.23	4.48	4.00	4.47	3.79	4.08	4.33	4.69
Phenylalanine	5.07	5.22	4.79	5.30	4.50	4.92	5.10	5.33

4.2 *IN VITRO* DIGESTIBILITY STUDIES

The results of *in vitro* protein and *in vitro* starch digestibility of whole, dehulled grain and sorghum products are reported in this section.

In vitro digestibility of starch and protein of whole and dehulled sorghum grain is given in Table 21.

Table 21: *In vitro* digestibility of starch and protein in whole, traditionally and mechanically dehulled sorghum grain

	Starch digestibility %	Protein digestibility %
Whole	11.2	73.0
Traditionally dehulled	18.3	83.8
Mechanically dehulled	20.5	78.9
LSD_{05}	4.35	5.92

LSD_{05} - Least significant difference at 5% level.

The *in vitro* starch digestibility showed a significant ($P<0.05$) increase on dehulling when compared to whole grain. Though mechanically dehulled grain flour had a higher starch digestibility compared to traditionally dehulled the increase here was not significant ($P>0.05$).

Mechanical and traditional dehulling resulted in an increase in *in vitro* protein digestibility. The traditionally dehulled grain flour had a higher digestibility value when compared to mechanically dehulled but the increase was not significant.

In vitro starch and protein digestibility of sorghum products is given in Table 22.

Table 22: The *in vitro* digestibility of whole and dehulled sorghum grain and their products

	Starch digestibility %		Protein digestibility %	
	W	D	W	D
Flour	11.2	20.5	73.0	78.9
Parched	55.7	-	49.4	-
Popped	83.2	-	66.9	-
Malted	46.8	-	86.4	-
Germinated	43.0	-	84.1	-
Parboiled	25.4	-	30.4	-
Boiled	46.1	44.5	23.9	22.3
Roti	61.8	58.6	44.4	46.3
Biscuit	59.8	54.2	34.1	34.8
Dosa	92.0	86.3	52.1	53.7
Idli	78.9	75.4	72.9	77.8
LSD_{05}	4.35	4.35	5.92	5.92

W - Whole D - Mechanically dehulled.

LSD_{05} - Least significant difference at 5% level.

A significant increase in starch digestibility was observed when whole and dehulled grain flour was subjected to various treatments. Digestibility differences were also observed among products studied. Highest digestibility values were observed for fermented products. Popped sorghum also gave a very high starch digestibility value. Boiled, germinated and malted sorghum had lowest starch digestibility values.

In vitro protein digestibility values decreased significantly in most cases when whole and dehulled flour were subjected to various treatments. Malting and germinating increased the digestibility significantly ($P<0.05$). Idli (fermented and steamed product) prepared from whole and dehulled grain had digestibility values similar to untreated flour.

4.3 BIOAVAILABILITY STUDIES

In this section the results of the bioavailability studies are presented.

4.3.1 Weight Gain, Nitrogen Absorption, Digestibility Coefficients and NPU of Whole and Dehulled Sorghum

Weight gain, nitrogen intake and nitrogen absorption in rats fed whole and dehulled sorghum flour during the experimental period is reported in Table 23.

Table 23: Weight gain, nitrogen intake and absorption in rats fed whole and dehulled sorghum

	Weight gain/rat in 10 days (g)	Nitrogen intake/rat in 10 days (mg)	Nitrogen absorbed (mg)	Nitrogen absorbed (%)
Whole	5.4	668	555	83.1
Traditionally Dehulled	2.9	595	509	85.5
Mechanically Dehulled	3.5	672	594	88.4
LSD_{05}		120.96		3.72

LSD_{05} - Least significant difference at 5% level

The weight gain was highest among the rats fed whole sorghum diet and nitrogen absorbed was 83%. Rats fed dehulled grain diets showed lesser weight gain, and rats on traditionally dehulled grain diet had the lowest weight gain. The percent nitrogen absorption was highest in the mechanically dehulled grain diet (88.4%).

Net protein utilization (NPU), true protein digestibility (TD), digestible energy (DE), and dry matter digestibility (DMD), were calculated from rat feeding trials using whole and dehulled sorghum flour and the results are presented in Table 24.

Table 24: NPU and digestibility coefficients of whole and dehulled sorghum grain flour as determined by rat feeding trials.

	NPU	TD	DE	DMD
Whole	54.1	92.0	91.8	91.9
Traditionally dehulled sorghum flour	45.4	95.6	94.7	94.1
Mechanically dehulled sorghum flour	47.1	97.4	94.3	94.8
LSD_{05}	4.80	3.62	1.32	1.69

LSD_{05} - Least significant difference at 5% level.

On dehulling the NPU decreased significantly ($P<0.05$). There was no significant difference between the NPU values of traditionally and mechanically dehulled flour.

Mechanical dehulling increased TD significantly, traditional dehulling also resulted in an increase in digestibility though not significantly. There was no significant difference in TD values between the dehulling methods.

DE and DMD increased significantly ($P<0.05$) on dehulling but no significant difference was observed between dehulling methods.

4.3.2 Weight Gain, Nitrogen Absorption, Digestibility Coefficients and NPU of Processed Sorghum Products

Weight gain, nitrogen intake and absorption in rats fed sorghum products prepared from whole and dehulled grain is given in Table 25.

Table 25: Weight gain nitrogen intake and absorption in rats fed products prepared from whole and dehulled sorghum grain

	Weight gain/rat in 10 days (g)		Nitrogen intake (mg)		Nitrogen absorbed (mg)		% Nitrogen absorbed	
	W	D	W	D	W	D	W	D
Flour	5.4	3.5	668	672	555	594	83.0	88.4
Parched	2.4	-	563	-	516	-	79.0	-
Popped	1.4	-	615	-	446	-	75.8	-
Malted	3.4	-	720	-	583	-	81.0	-
Germinated	6.1	-	723	-	588	-	81.9	-
Parboiled	3.7	-	678	-	511	-	75.4	-
Boiled	5.6	2.6	724	717	479	574	66.2	80.5
Roti	5.2	4.0	612	672	495	563	81.0	84.0
Biscuit	-0.8	-2.1	631	496	483	390	76.6	78.6
Dosa	5.1	-1.2	683	502	539	379	78.9	79.5
Idli	6.1	3.6	647	600	489	478	77.9	79.8
LSD_{05}			120.86				3.72	

W - Whole

D - Mechanically dehulled

LSD_{05} - Least significant difference at 5% level.

4.3.2.1 Weight gain. Rats fed biscuit lost weight and loss of weight was more in the rats fed biscuits prepared from dehulled grain. Rats fed dosa prepared from dehulled grain also lost weight. Among the other diets rats showed gain in weight from 1.4 (popped sorghum) to 6.1 g (germinated sorghum and idli prepared from whole grain) in 10 days of experimental period.

4.3.2.2 Nitrogen Intake. The nitrogen intake of rats varied considerably among the different diets. The nitrogen intake of rats on biscuit and dosa (both prepared from dehulled flour), was significantly lower than the other groups.

4.3.2.3 Nitrogen absorption. Nitrogen was most efficiently absorbed by untreated mechanically dehulled flour which was significantly higher than untreated whole grain flour ($P<0.05$). Among whole grain products, decrease in the nitrogen absorption was significant in popped, parboiled, boiled, baked (biscuit) and fermented (idli) products when compared to whole grain flour. All sorghum products showed a decrease in nitrogen absorption and the decrease was significant in all products prepared with dehulled grain when compared to dehulled grain flour. All dehulled products had a higher nitrogen absorption when compared to the same product prepared from whole grain but the increase was not significant except in the case of boiled sorghum where the increase was significant ($P<0.05$).

NPU, TD, DE, DMD values of sorghum products are given in Table 26.

Table 26: NPU and digestibility coefficients of processed sorghum products as determined by rat feeding trials.

	NPU (%)		TD (%)		DE (%)		DMD (%)	
	W	D	W	D	W	D	W	D
Flour	54.1	47.1	92.0	97.4	91.8	94.3	91.9	94.8
Parched	48.5	-	88.2	-	93.9	-	91.7	-
Popped	38.4	-	85.9	-	91.8	-	89.1	-
Malted	49.8	-	89.3	-	93.8	-	91.4	-
Germinated	56.8	-	89.6	-	92.1	-	91.2	-
Parboiled	46.1	-	84.1	-	92.9	-	91.8	-
Boiled	50.5	44.8	74.6	88.5	89.7	94.7	88.6	94.0
Roti	50.2	43.7	90.8	92.8	93.3	94.4	92.8	94.0
Biscuit	41.2	27.0	86.1	87.2	91.7	93.6	91.5	93.5
Dosa	50.4	31.6	87.5	89.1	91.6	91.9	91.3	92.0
Idli	58.3	42.7	86.3	89.7	90.5	93.7	90.8	93.6
LSD_{05}	4.80		3.62		1.32		1.69	

W - whole

D - mechanically dehulled

LSD_{05} - Least significant difference at 5% level

4.3.2.4 Net Protein Utilization. Subjecting whole and dehulled grain and flour to various treatments resulted in a general lowering of NPU values (figures 1-4) except in case of germination and fermentation where the values increased though not significantly (P>0.05).

4.3.2.5 True Protein Digestibility. True protein digestibility decreased in all treated grains and products when compared to untreated flour but the decrease was significant only in popping, par boiling, boiling, baking (biscuit) and fermentation. In other treatments the decrease was not significant. Dehulled grain products had slightly higher values for TD when compared with whole grain products though the increase was not significant (P>0.05) except in the case of boiling where a significant (P<0.05) difference was observed between whole and dehulled product (figures 5-8).

4.3.2.6 Digestible Energy. Digestible energy increased significantly (P<0.05) on parching, malting and in open pan baking (roti) and decreased on boiling. The rest of the treatments did not affect the DE values. Dehulled grain products, boiled, biscuit and idli (fermented) had significantly higher DE values when compared to the same products prepared from whole grain flour.

3.2.7 Dry Matter Digestibility. Dry matter digestibility decreased on popping and fermenting (dosa). Dehulled grain products (boiled, baked and fermented - idli) showed significantly ($P<0.05$) higher DMD values when compared to products prepared from whole grain.

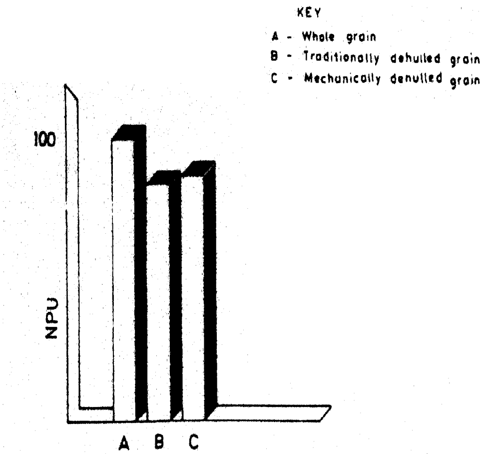

Figure 1: NPU of whole and dehulled grain
[expressed as % of whole grain]

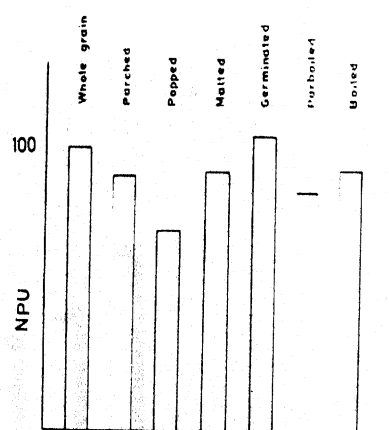

Figure 2: NPU of whole grain sorghum products
[expressed as % of whole grain]

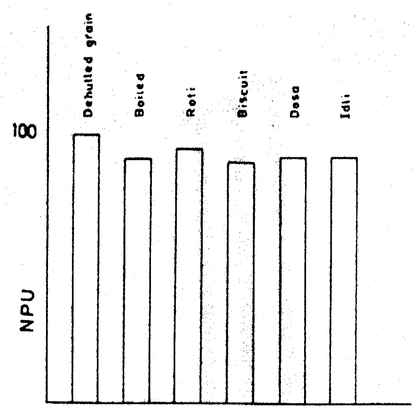

Figure 3: NPU of dehulled sorghum grain products
[expressed as % of dehulled grain]

Figure 4: NPU of whole and dehulled sorghum products.
[expressed as % of whole sorghum grain]

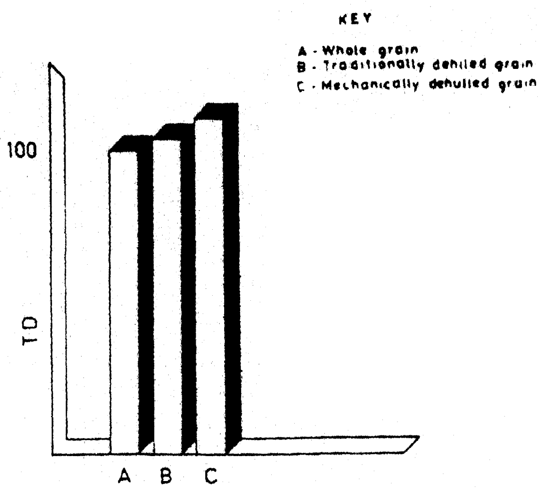

Figure 5: TD of whole and dehulled grain.
[expressed as % of whole grain]

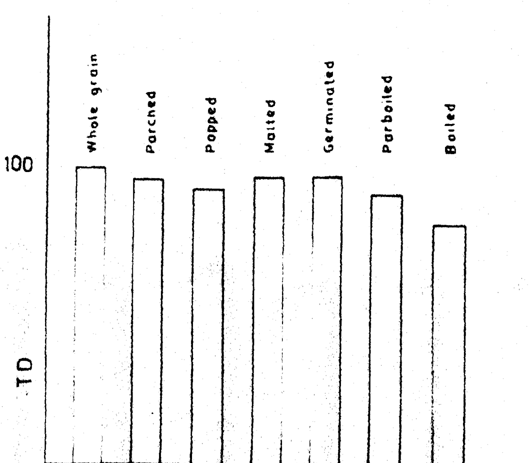

Figure 6. TD of whole sorghum grain products
[expressed as % of whole grain]

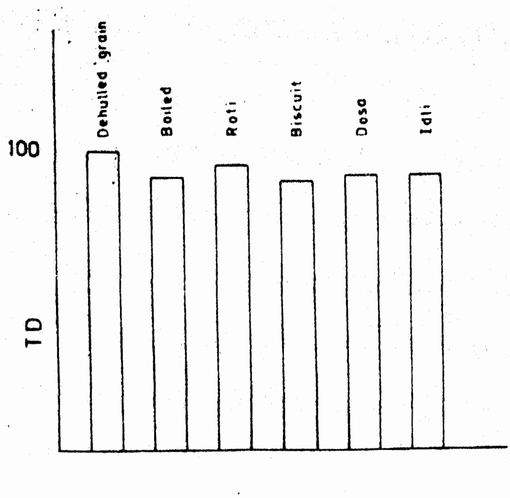

Figure 7: TD of dehulled sorghum grain products.
[exepressed as % of dehulled grain flour].

Figure 8: TD of whole and dehulled sorghum products.
[expressed as % of whole grain]

CHAPTER V

DISCUSSION AND CONCLUSION

The sorghum variety used in this study M35-1 (Maldandi) is grown in the post rainy season and the grain matures in 125-130 days (ICAR 1980). The kernels of sorghum M35-1 are large, with a thin white pericarp and an intermediate endosperm texture. The characteristic size, shape and lustre of Maldandi grain sets the standard for sorghum quality in India and it also costs the most in the grain market (Rooney and Murthy 1982). Sorghum M35-1 is the most commonly prepared cultivar for roti (unleavened bread) in India (Rooney and Murthy 1982).

5.1 Proximate Composition

5.1.1 Whole and Dehulled Grain

The proximate composition of the grain under study was well within the range of values reported by several authors.

Sorghum dehulled traditionally and mechanically showed differences in chemical composition. The dehulled grain flour had significantly lower fat and fibre content when compared to whole grain flour. The protein and starch contents in both the dehulled grains were similar when values were expressed as percent yield of the dehulled grain, but when protein and starch contents were expressed as percent of whole grain the content of these two nutrients in the mechanically dehulled grain were significantly higher than the traditionally dehulled grain. The ash, fat and fibre levels did not display such a change when expressed in terms of the whole grain.

Some difference in chemical composition was also observed between traditional and mechanical dehulling. Ash and fat contents were significantly lower in traditionally dehulled grain than in mechanically dehulled. Germ has the highest percentage of ash and oil content (Hubbard _et al_ 1950, Riechert and Youngs 1977). It is possible that more of the germ was removed in the traditional dehulling than in mechanical dehulling system. This might result in a decrease in ash and fat in the traditionally dehulled grain.

Farier _et al_ (1972) and Riechert and Youngs (1977) have compared the chemical composition of mechanically and traditionally dehulled flour. Farier _et al_ (1972) found the chemical composition of mechanically and traditionally dehulled flour almost identical except for a 11.5% decrease in protein content on mechanical dehulling. Riechert and Youngs (1977) have reported that traditionally and mechanically dehulled grains did not differ markedly in their protein content but ash and oil contents were higher in traditionally dehulled grain flour.

Almost identical values for chemical composition (except for fat and ash) of hand decorticated, mechanically dehulled (Munck _et al_ 1982) and traditionally dehulled (Eggum _et al_ 1982) Lulu D, a variety of sorghum has been reported as shown below.

Table 27: Proximate composition of one variety of sorghum (Lulu D) by hand decortication, mechanical dehulling and traditional dehulling

	% dry matter				
	Starch	Fibre	Fat	Ash	Protein
Hand decorticated*		0.6	0.5	0.31	12.2
Decorticated in UMS DVA Dehuller*		0.6	1.1	0.69	12.1
Traditionally dehulled**	85.4	0.6	0.5	0.31	12.2

* Munck _et al_ 1982

** Eggum _et al_ 1982.

It is indeed difficult to compare the results of mechanically and traditionally dehulled grain reported by different authors with the results obtained in the present study because the methodology involved in traditionally dehulling differ greatly from region to region, different mechanical dehullers have been used in different studies and also because the chemical composition of the flour depends to a great extent on the extraction rate.

5.1.2 <u>Products Prepared from Whole and Dehulled Grain</u>

The chemical composition of the products prepared from whole and dehulled grain showed significant variation between treated and untreated and also among treatments.

1.2.1 Cooking. Eggum et al (1983) reported that cooking resulted in higher analytical values for crude fibre, but lower values for starch and sugar. When dehulled flour was cooked the proximate analyses did not show any significant changes (Eggum et al 1982).

Changes in the carbohydrate composition and content on processing has also been reported by McNeill et al (1975). Significant differences ($P<0.05$) were observed in the percent of total carbohydrates, ethanol soluble carbohydrates and starch between dry ground meal and treated samples (reconstituted, steam flaked and micronized) and also between treatments. In the present study the starch level was found to decrease in both whole and dehulled grains on cooking. No significant changes were observed in the crude fibre levels.

1.2.2 Fermentation. Kazanas and Fields (1981) reported proximate analysis for fermented and unfermented sorghum meal. Though differences in analytical values for protein, fat, fibre and ash were observed between treated and untreated samples, the changes were insignificant. The results of the present study indicated significant differences in the starch and protein levels on fermentation. Hamad and Fields (1979) have reported a decrease in percent crude protein on fermentation in wheat, oats and maize.

5.1.2.3 Germination. Wu and Wall (1980) found that normal sorghum germinated for first 3 days did not affect the chemical composition much but on the sixth day of germination the protein increased and starch decreased. In the present study (germinated for 48 hours) though no significant increase was observed in protein content, the starch content had decreased significantly on germination.

5.2 AMINO ACID COMPOSITION

5.2.1 Whole Grain

Lysine, methionine + cystine and threonine have been reported to be limiting in sorghum grain (Waggle *et al* 1966, Virupaksha and Sastry 1968 and Antongiovani *et al* 1980). In the present study the levels of these amino acids were found to be 2.4 g for lysine, 3.6 g for methionine + cystine and 3.1/16 gN for threonine. Swaminathan *et al* (1970) in a study reported 2.5 g of lysine, 4.3 g methionine + cystine and 2.3 g/ 16 gN of threonine to be present in the M35-1 sorghum variety.

According to the WHO (1973) the desired level of sulphur amino acid in protein is 3.4 g/16 gN. Therefore it appears that sorghum M35-1 variety is not limiting in sulphur amino acids, though lysine and threonine contents are less than the desired levels.

5.2.2 Dehulling and Amino Acid Composition

On dehulling, lysine appears to be the main amino acid affected to a great extent. On traditional dehulling 21% and on mechanical dehulling 16.5% lysine was lost as observed in the present study. Pushpamma and Chittemma Rao (1981) have found that there is a 12.5% loss in lysine and 23.5% loss in methionine on traditional dehulling. Eggum et al (1983) reported 9% and 16% decrease in lysine content on dehulling, in two different varieties of sorghum. In another study Eggum et (1982) reported the amino acid composition of whole and decorticated sorghum by giving a mean of 5 local Tanzanian varieties and the lysine loss on dehulling was 36%. In the same study, Eggum et al (1982) have reported lysine content of hand dissected endosperm of US hybrid sorghum to be 43% less than whole grain. In another study Haikerwal and Mathieson (1971) have reported a 25.5% loss in lysine content in hand dissected endosperm. From such varied results it is difficult to come to any conclusion, for, the decrease in lysine, on dehulling could vary depending upon the extent of pericarp removal and also the proportion of germ removed during decortication.

5.2.3 Sorghum Products and Amino Acid Composition

Lysine again was found to be the amino acid most affected when whole and dehulled grain were subjected to various treatments. Parching, parboiling and boiling whole grain affected lysine the least. Eggum *et al* (1982) reported the amino acid composition of *ugali*, a boiled Tanzanian food, in which lysine content was not affected in the cooked product.

Twenty eight percent loss of lysine was observed on popping the grain in the present study. This could be due to the high temperature (215°C) that was used for popping. Shiau and Yang (1982) found that micronizing sorghum at temperature 102°, 250° and 282°C resulted in a loss of 17%, 33% and 28% respectively, of lysine.

Dosa (fermented and pan fried product) prepared with whole and dehulled grain suffered a loss of 25-28% in lysine and the loss in *idli* (fermented and steamed) was 19%. El Tiney *et al* (1979) while evaluating the nutritive value of *kisra* (a fermented pan fried Sudanese food) reported a 24% loss of lysine in one of the varieties studied. Eggum *et al* (1980) reported the amino acid composition of *kisra* but lysine content of the product did not appear to be greatly affected. All dehulled products except *dosa* and biscuit had lysine content similar to that present in the untreated dehulled grain.

Biscuits and *dosa* prepared from whole and dehulled grain had very low values for lysine (39% loss observed). Mahajan and Pushpamma (1972) have reported destruction of lysine on baking (biscuits) and deep fat frying (*murku*) of sorghum products.

5.3 *IN VITRO* STARCH DIGESTIBILITY

5.3.1 Whole and Dehulled Grain

In the present study the *in vitro* starch digestibility (IVSD) was 11.1% in the whole grain. Osman *et al* (1970) reported IVSD of whole sorghum to be 16.7%. Mechanical and traditional dehulling increased starch digestibility significantly. Radha Pai and Pushpamma (1977) have observed that there was no significant difference in IVSD between whole and (traditionally) dehulled sorghum but in the present study it was found that even traditional dehulling resulted in a significant ($P<0.05$) increase in IVSD.

5.3.2 Sorghum Products

Various treatments given to whole and dehulled grain increased IVSD by several fold. The highest IVSD was observed for *dosa* (fermented and pan fried). An eight fold increase was observed for both whole and dehulled product. *Idli* prepared whole grain also had a seven fold increase in IVSD.

Though the untreated dehulled flour had significantly higher IVSD values when compared to whole grain flour, such a digestibility difference was not observed when products were prepared from the whole and dehulled grain flour. The dehulled grain products had digestibility values similar to whole grain products except in the case of dosa and biscuit prepared from dehulled grain which had IVSD values significantly ($P<0.05$) lower than the same products prepared from whole grain. Kazanas and Fields (1981) have reported that fermentation resulted in an increase in carbohydrate availability. Carbohydrate availability was 16.7% in nonfermented and 31.8% in fermented product and the difference was significant at 1% level. Walker et al (1970) and McNeill et al (1975) have also noted the increase in IVSD on processing.

5.4 IN VITRO PROTEIN DIGESTIBILITY

In vitro protein digestibility (IVPD) using Axtell et al (1981) pepsin digestibility method showed digestibility difference between whole and processed sample as was suggested in their paper (Axtell et al 1981). On boiling whole grain, IVPD decreased by 67% and in dehulled grain by 72%. Other treatments affected IVPD to a lesser degree as follows: parching 32%, popping 8%, parboiling 58%, roti prepared from whole grain 39%, roti prepared from dehulled grain 36.5%, biscuits prepared from whole grain 53% and biscuits prepared from dehulled grain

52%. Idli prepared from whole and dehulled grain had IVPD similar to untreated grain. Higher IVPD values for fermented products have been reported by Axtell et al (1981). Kazanas and Fields (1981) have also found that protein availability (pepsin digestion) increased significantly ($P<0.01$) on fermentation. Malted grain had 15% and germinated grain 13% higher IVPD than whole grain. If the availability of proteins are to be predicted from IVPD data, then it appears that fermented (idli), malted and germinated sorghum have better protein availability when compared to the other products assayed in the present study.

5.5 BIOAVAILABILITY STUDIES

Protein quality relates to the efficiency with which various food proteins are used for synthesis and maintenance of tissue proteins (Jansen 1978). The evaluation of food protein quality normally proceeds from the simple to the more complex. The evaluation starts with nitrogen and amino acid analysis, moves through a series of specific chemical measurements and ends up with biological tests. Though animal assay are used widely to evaluate protein quality, they do have limitations which must be kept in mind while interpreting the data (Pellett and Young 1980). The various bioassay methods used for assessing protein quality and the drawbacks have been discussed by Pellett and Young (1980). Of these, the method based on nitrogen retention was selected, for use for the present bioavailability studies.

5.5.1 Net Protein Utilization

Several methods use nitrogen retention as the dependent variable in a protein quality assay. The simplest of this is the net protein utilization (NPU) which measures the difference in carcass nitrogen between rats fed a test protein and those fed a protein free diet. This method can rank protein and can discriminate protein quality to a moderate accuracy (Pellett and Young 1980).

Of the many procedures tried out, NPU is now the most used. This is the proportion of ingested nitrogen that is retained in the body under specific conditions. NPU is a combined measure of digestibility and of the efficiency of utilization of the absorbed amino acids (WHO 1973). Collection of fecal material during the assay period enables separate estimation of digestibility values (Pellett and Young 1980).

5.6 NUTRITIONAL VALUE OF SORGHUM AND SORGHUM PRODUCTS

5.6.1 Whole Grain

The NPU value obtained for whole sorghum grain flour in the present study was 54.1 (protein level 8%). The true protein digestibility (TD) was 92.0%, the digestible energy 91.8 and dry matter digestibility 91.9% in the whole sorghum grain flour. An NPU of 28.6 was reported by Harden et al (1976) for whole sorghum diet at 8% protein level. NPU values of 48.6-57.0 were reported by Eggum et al (1982 and 1983) for four different varieties of sorghum grain. Net protein retention (NPR) values 1.60, 1.71 and 1.61 were obtained for three varieties of sorghum by Sikka and Johari (1979). NPR is reported to have a highly significant correlation with NPU (Bender and Doell 1957).

The true protein digestibility has also been reported by Eggum et al (1982, 1983). The TD values for whole grain ranged from 94.5-95.8% in four different varieties. The digestible energy ranged from 89.6-90.6% in the same varieties. The dry matter digestibility studied in 7 varieties of sorghum (Ilory and Conrad 1976) was found to range between 83.2-85.3%.

From the above information it can be said that though sorghum protein is not very efficiently retained in the body but the energy and protein digestibility values obtained from animal experimentation are good. In fact the values compare well with those obtained from rice, wheat and maize (Eggum et al 1982).

5.6.2 Dehulled Grain

On dehulling, the NPU decreased significantly, from 54.1 in whole grain to 47.1 for mechanically dehulled and 45.4 for traditionally dehulled grain flour. The true protein digestibility (TD), digestible energy (DE) and dry matter digestibility (DMD) for traditionally dehulled grain was 95.6, 94.7 and 94.1% respectively and for mechanically dehulled grain it was 97.4, 94.3 and 94.8% respectively. Narayan Rao et al (1958) and Eggum et al (1982, 1983) have also reported similar results. Weight gain was much less in the rats fed the dehulled grain diet but the nitrogen absorption (%) was higher in dehulled grain diet with the mechanically dehulled diet having the highest nitrogen absorption. Though dehulling reduced the NPU, but the TD, DE and DMD increased significantly. The NPU was lowered due to the loss of the essential amino acid lysine, with the bran fraction. And the increase in the digestibility values were probably due to the removal of bran which has a high level of fibre. The difference in the TD, DE and DMD and NPU values obtained between the dehulling methods were not significant.

6.3 Sorghum Products Prepared from Whole Grain

3.1 Parched Sorghum. Rats on parched sorghum showed a total gain in weight of 2.4 g in 10 days. This was considerably lower than the rats on untreated whole sorghum diet which showed a weight gain of 5.4 g in 10 days. The NPU was 48.5 which was significantly lower than the NPU of whole grain though the lysine level both in whole and parched grain were similar. The lowering of NPU could probably be explained by slightly lower nitrogen intake and significantly lower nitrogen absorption. The TD of parched sorghum was also lower but the digestible energy was significantly higher when compared to whole grain flour. Acharya et al (1942) have reported that parched sorghum had a higher BV than unparched sorghum, but this was not found to be so in the present study.

6.3.2 Popped Sorghum. Popped sorghum diet was still less efficient in maintaining weight gain in rats. The total weight gain in 10 days was only 1.4 g. The NPU was 38.4. The percent nitrogen absorption and TD was significantly lower than whole sorghum. The low NPU could be explained by the 28% loss in the total lysine. The lysine loss could have occurred due to the high temperature (215^{o}C) that was used for popping the grain. The digestible energy of the popped sorghum diet was similar to the whole grain diet but the dry matter digestibility was significantly lower. Of all the whole grain products popped sorghum had the lowest nutritive value.

6.3.3 Malted Sorghum. The NPU of malted sorghum was not significantly lower than whole grain diet, though it was lower than the NPU of germinated sorghum diet. The weight gain of the rats on malted sorghum diet was 3.4 g in 10 days and this was 37% lower than the rats on whole grain diet. The nitrogen absorption and TD was not significantly different from the whole grain diet. The TD of malted sorghum was similar to the TD of germinated sorghum and sorghum roti. The digestible energy of malted sorghum was significantly higher than the whole grain diet.

6.3.4 Germinated Sorghum. Germinated sorghum diet resulted in higher weight gain in rats. The rats gained 6.1 g in 10 days. Except rats on idli diet, prepared with whole sorghum, no other diet tested in the present study supported growth to this extent. The NPU was also high though it was not significantly higher than whole grain diet. The nitrogen absorption and TD was comparable to malted sorghum diet. Though the total lysine content in malted and germinated sorghum were similar the weight gain and NPU were higher in germinated sorghum than malted sorghum. This could be either due to the increase in available lysine or due to increased availability of the protein itself. Wang and Fields (1978) and Hamad and Fields (1979) have reported that there is an increase in relative nutritive value on germination in sorghum as well as in other cereal grains. They have also reported an increase in lysine level on germination but the minimum period required for lysine level to increase is 3 days under favourable conditions. In the present study sorghum was germinated for 2 days only, so the increase in total lysine was not observed and also significant increase in NPU was not observed though there was a slight increase.

6.3.5 Parboiled Sorghum. The weight gain in rats fed parboiled sorghum diet was 3,7 g in 10 days. The NPU was significantly lower than whole grain or germinated sorghum diet. The total lysine level was the same as whole grain but inspite of that the NPU was low. This may be explained by the fact that nitrogen absorption and TD was significantly lower than whole grain, except boiled sorghum, parboiled sorghum had the lowest protein digestibility. The digestible energy and dry matter digestibility was similar to the other sorghum products.

5.6.4 Sorghum Products Prepared from Whole and Dehulled Grain

6.4.1 Whole Grain-Boiled. Boiled whole grain when fed to rats resulted in a weight gain of 5.4 g in 10 days. The NPU was 50.5 which was not significantly different from the NPU of whole grain but it was significantly lower than germinated sorghum. The nitrogen absorption,TD, DE and DMD were significantly lower than that of any other product. Eggum et al (1983) have reported similar NPU values for ugali, a Tanzanian dish prepared by cooking sorghum flour in water. The digestibility values reported were also lower than the other sorghum products tested. FAO (1970) reported a personal communication from Drayer (1963) that sorghum cooked, dried and fed to rats gave an NPU of 55.8 and BV of 73.2.

5.4.2 Dehulled Grain-Boiled. When dehulled grain was boiled it gave a much lower NPU value (44.8) when compared to boiled whole grain. Though NPU was not significantly lower than the NPU of untreated dehulled grain flour. The 16.5% loss of lysine on dehulling is probably the cause of the low NPU value. The TD of boiled dehulled grain increased significantly when compared to boiled whole grain. The DE and DMD of dehulled boiled grain was similar to that of untreated dehulled grain but the TD was significantly lower. The removal of bran probably resulted in an increase in the protein digestibility. The weight gain of rats on dehulled boiled sorghum diet was 2.6 g in 10 days.

5.4.3 Whole Grain-Roti. The NPU of roti prepared from whole grain was 50.2 which is similar to NPU values obtained from malted sorghum, boiled (whole grain) sorghum and dosa prepared from whole grain and not significantly different from the NPU value of untreated whole sorghum grain flour. The weight gain in rats fed roti diet was 5.2 in 10 days. Weight gain again was similar to the rats fed whole sorghum or boiled whole sorghum diet. Both weight gain and NPU of roti was less than that observed in germinated sorghum. The nitrogen absorption of the roti diet was high and the TD was highest among all the whole sorghum products.

6.4.4 Dehulled Grain-Roti. The weight gain of rats on roti, prepared from dehulled grain was 4.0g in 10 days. Rats fed roti prepared from dehulled grain showed the highest weight gain among all the dehulled grain diets studied. The NPU was 43.7 which was not significantly lower than untreated dehulled grain flour. Low NPU values could be expected because of the initial low lysine level in the dehulled grain flour. Like roti prepared from whole grain, roti prepared from dehulled grain had high digestibility values, it had the highest nitrogen absorption and TD levels among all the dehulled grain products studied. Chawla and Kapoor (1982) have found that the losses of amino acid due to chapati making were negligible. This is in accordance with the present study.

.4.5 Whole Grain-Biscuit. Biscuits prepared from whole sorghum grain failed to support growth in rats. There was 0.8 g loss in weight of the rats in 10 days. The NPU value was significantly lower than the untreated whole grain, and had the lowest NPU among all the whole grain products except for popped grain which had an NPU lower than biscuits. Both nitrogen absorption and TD was significantly lower than untreated whole grain flour.

4.6 Dehulled Grain-Biscuits. The NPU of biscuits prepared from dehulled grain was significantly lower than all the other dehulled products except dosa prepared from dehulled grain where the NPU values were also quite low. When biscuits prepared from dehulled grain was fed to the rats they lost 2.1 g of weight in 10 days. The nitrogen intake of rats on biscuits prepared from dehulled grain was significantly low when compared to the nitrogen intake of rats fed untreated dehulled grain flour or to biscuit diet prepared from whole grain. The digestibility value was slightly higher for biscuits prepared from dehulled grain than in the biscuits prepared from whole grain. The DE and DMD of biscuits prepared both from whole grain and dehulled grain were similar to the DE and DMD of the respective untreated flour.

The low nutritive value of biscuits could be due to modifications in the basic recipe, baking temperature and time. Normally biscuits are prepared with 30-35% fat but in the present study the fat level was lowered to 10% in an attempt to keep all the diets isocaloric. Again, the normal baking temperature is 180°C and baking time 10-15 minutes. But in the present study due to the low level of fat in the dough, biscuits required a higher temperature and longer time to reach the desired level of doneness. The baking temperature was increased to 250°C and baking time to 25 minutes. Baking at high temperature for 25 minutes probably resulted in the destruction or unavailability of important nutrients.

That baking affects the availability of amino acids and especially lysine has been reported by several authors. Prabhavathi et al (1973) have reported that PER values of unbaked biscuit mixtures were higher than PER values for biscuits, which were lower by 13-35%. They also found that the PER of commercial biscuit was 0.98. Zombade and Sathe (1977) reported a loss of 40.4% available lysine when a fish meal was subjected to dry (oven) heating. The loss of available lysine was 30% when groundnut cake was subjected to wet (autoclaving) heating. Faridi et al (1982) have also found that the process of baking lowered the PER value of Iranian flat breads.

Mahajan and Pushpamma (1972) in a study reported that while the PER of untreated whole sorghum flour was 1.0, biscuit prepared from the flour had a PER of 0.5. On analysing the biscuit they found the available lysine to be low, so the lysine level was supplemented in such a way so that it was similar to the level in untreated flour. But when the lysine supplemented sorghum biscuit was fed to rats it gave a PER of 0.6 and failed to attain the PER level of untreated flour. It is probable that something other than the availability of lysine is affecting the protein utilization from sorghum biscuits. Hurrell and Carpenter (1981) have explained some important interaction of food components on processing in a simple schematic form as shown in the following page (figure 9)

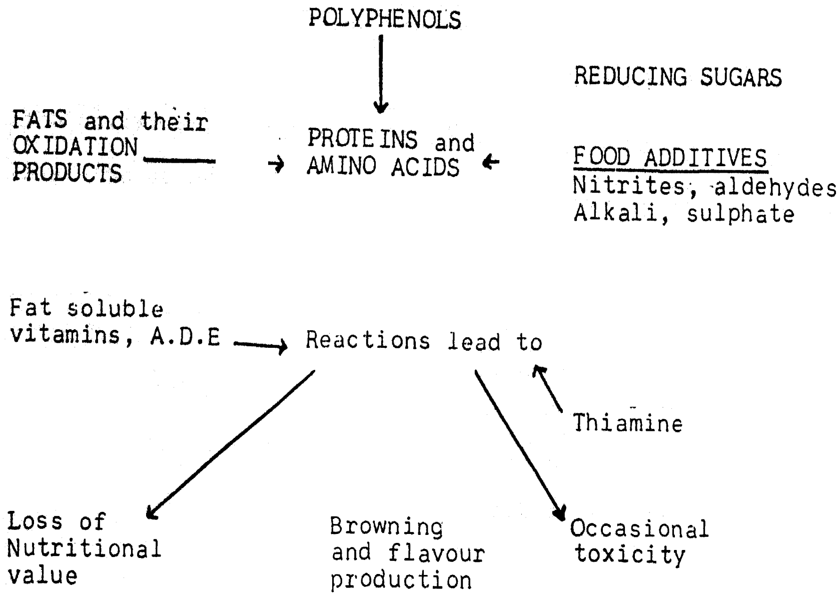

Figure 9: Some important interactions of food components on processing

4.4.7 Whole Grain-Dosa. The weight gain and NPU of *dosa* prepared from whole grain was similar to the boiled product and *roti* prepared from whole grain and also to the untreated whole grain. The nitrogen absorption and the true digestibility was significantly lower than the untreated grain. The DE and DMD was similar to the whole grain.

Eggum *et al* (1983) reported the nutritive value of *kisra* - a fermented product from Sudan. The NPU was similar to the values obtained for dosa (whole grain) in the present study. Au and Fields (1981) and Kazanas and Fields (1981) observed an increase in percent RNV in fermented sorghum, when sorghum was fermented at 35°C for 7 days. An increase in nutritive value was not observed in the present case as the batter was fermented for 16 hours. It has been reported that the amino acid content of a particular food may decrease in the first few hours of fermentation as the amino acids would be metabolised by micro organisms during active growth at a faster rate than they were being formed from the protein by native proteases. Later when fermentation proceeds to 48 and 72 hours the amino acids accumulated as the rate of active fermentation and growth subsided (Morimoto 1966).

.4.8 Dehulled Grain-Dosa. Dosa prepared with dehulled grain was unable to support growth in rats. The rats on this diet lost 1.2 g weight in 10 days. The NPU was also low. The loss of weight and low NPU could be due to the low intake of nitrogen. The nitrogen intake was significantly lower than the rats on the dosa diet prepared with whole grain. The intake was similar to the rats on biscuit diet prepared with dehulled grain. The nitrogen absorption was significantly lower than the untreated dehulled grain but similar to the absorption observed with the other products. The DE and DMD was significantly lower than the untreated dehulled grain.

The reason for the low food intake was not understood. There is some factor which limits the rats' ability to increase food intake to obtain more protein (Prestonmercer 1981).

Probably this product was not very well accepted by the rat. Also the lysine level in this product was more severely affected than the other products studied. Moreover the damage caused to lysine is usually not completely detected by the conventional Moore and Stein chromatograms (Hurrell and Carpenter 1981).

.4.9 Whole Grain-Idli. Rats on idli (fermented and steamed product) diet (whole grain) showed a weight gain of 6.1 g in 10 days, which is the maximum weight gain recorded in this study. Germinated sorghum also resulted in similar weight gain. The NPU was also the highest recorded in this study though it was not significantly different from germinated sorghum or untreated whole grain. But the NPU was significantly higher than all the other products studies. The nitrogen absorbed and TD was significantly lower than untreated grain but DE and DMD were similar.

4.10 Dehulled Grain-Idli. The weight gain of rats on dehulled grain idli diet was 3.6 g in 10 days. The NPU was 42.7 which was not significantly lower than either the untreated dehulled grain flour or boiled grain or roti. It was significantly higher than biscuit and dosa prepared with dehulled grain. The nitrogen absorption and TD was higher in the idli diet prepared with dehulled grain than in the idli diet prepared with whole grain though the increase was not significant. The DE and DMD was comparable to the untreated dehulled grain. Though the NPU is low which is because of the initial low level of lysine in the dehulled grain, the digestibility values are quite encouraging.

,6.5 Correlation Between the Various Parameters Used for the Study and the General Findings of the Bioassay

Table 28: Correlation matrix

IVSD	1.0000					
IVPD	-0.1490	1.0000				
NPU	-0.3238	0.5463	1.0000			
TD	-0.0920	0.4095	0.0330	1.0000		
DE	-0.4706	0.1305	0.6777	-0.3427	1.0000	
DMD	-0.4764	0.1035	0.7467	-0.2401	0.8264	1.0000
	IVSD	IVPD	NPU	TD	DE	DMD

5.1 Net Protein Utilisation. Lysine content of the unproc sorghum and sorghum products were found to be significantly ($P<0.05$) correlated to the respective NPU values ($r = +0.776$) (figure 10). NPU was found to be significantly correlated also to DE and DMD ($r = +0.678$ and $+0.748$ respectively). The correlation between NPU and TD was positive but not significant. NPU and IVPD showed significant correlation ($r = +0.546$).

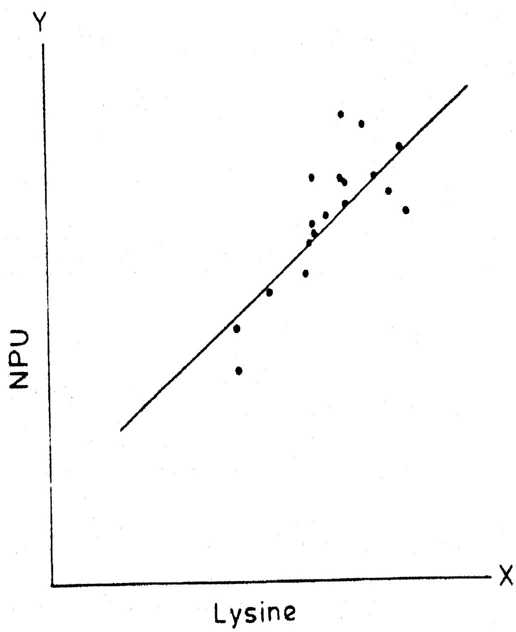

Figure 10: Scatter diagram of 18 lysine NPU pairs. r = 0.776.

5.2 True Protein Digestibility (TD). Negative correlation, was observed between TD and DE (r = -0.343). A significant correlation was noted between IVPD and TD (r= +0.410).

5.3 Digestible Energy (DE) and Dry Matter Digestibility (DMD). DE and DMD were found to be significantly correlated (r = +0.826), the IVSD was significantly and negatively correlated with both DE and DMD (r = -0.471 and -0.476 respectively).

6.6 Ranking of Sorghum Products

The fifteen sorghum products studied were ranked in the descending order. They were then divided into three groups, namely good, fair and poor. The first five considered good, the second five was fair and the last five was considered to be poor. The result of such ranking is reported in the following table.

Table 29: Ranking of sorghum products based on the availability of nutrients

	NPU		TD		NPU+ TD		NPU+TD+ DE+DMD		NPU+TD+ DE+DMD+ IVPD+IVSD		IVSD+ IVPD	
	W	D	W	D	W	D	W	D	W	D	W	D
Parched	F	-	F	-	F	-	F	-	F	-	F	
Popped	P	-	P	-	P	-	P	-	P	-	G	
Malted	F	-	G	-	G	-	G	-	G	-	G	
Germinated	G	-	G	-	G	-	F	-	G	-	F	
Parboiled	F	-	P	-	P	-	P	-	P	-	P	
Boiled	G	F	P	F	F	F	P	G	P	F	P	P
Roti	G	F	G	G	G	G	G	G	G	G	F	F
Biscuit	P	P	P	F	P	P	P	F	P	P	P	P
Dosa	G	P	F	F	F	P	F	F	F	F	G	F
Idli	G	P	P	G	G	F	P	G	F	G	G	G

G - Good
F - Fair
P - Poor

W - Whole
D - Mechanically dehulled

When NPU and TD ranking are considered seperately no clear picture is possible. But NPU and TD, NPU, TD, DE and DMD and NPU, TD, DE, DMD, IVSD and IVPD show a similar trend in the ranking. Roti, malted and germinated sorghum appear to have good ranking in most cases. Idli and boiled (dehulled grain) sorghum rank well when the over all ranking is considered.

Boiled whole grain, popped and parboiled grain and biscuits prepared with whole and dehulled grain consistantly appear to be of poor quality. The other products show fair ranking, dosa and parched grain come under this group. Though idli prepared with whole grain got a good ranking when NPU and NPU + TD were considered but it turned out to be of fair or poor rank in most other case, which probably indicates that the overall protein quality was good but the energy and dry matter availability was not as good.

Thus, germination appears to be reasonably good method for increasing protein quality and it imparts good digestibility also. Wang and Fields (1978) suggested that germination could be used to produce a more nutritious ingredient from which food could be prepared for the developing countries. The use of sprouted sorghum as a vegetable and salad or dried and ground flour could be used in traditional food receipes has been suggested by Wu and Wall (1980). Through proper technology, germinated sorghum flour could be incorporated in bakery product thus improving the quality of baked product (Wall and Bietz ,1980).

Results obtained on boiled sorghum seem to be a little controversial. Though NPU of whole boiled sorghum is 50.5, its digestibility is low and on boiling dehulled grain the digestibility goes up considerably but at the cost of NPU which decreases. MacLean et al (1981) in an experiment with children fed sorghum gruel, found that nitrogen retention and digestibility of whole boiled sorghum was very poor and concluded that boiled sorghum was unsuitable for children as an energy or protein source. Probably this is where dehulling the grain and supplementation of sorghum diet with other food could play a role. Supplementing could help in increasing the NPU and dehulling the sorghum would increase the digestibility. Pushpamma et al (1979) have shown that supplementing sorghum with pulses gave encouraging results with children. Supplementation of sorghum with leafy vegetables (Talwalkar and Patel 1970) or other cereal grains (Obizoba et al 1979) can also improve the nutritive value of sorghum proteins. The effect of supplementation on dehulled sorghum has not been reported so far. Such a study will be worth taking up.

Roti prepared with whole sorghum seems to be good, as in the present study it gave an NPU of 50.2 and a high digestibility value. On dehulling, digestibility further increased but then again at the cost of NPU, which decreased. Since roti is rarely consumed without some other dish to go with it, probably a suitable combination could be arrived at. Since highly acceptable rotis are obtained with sorghum, probably this process could be applied to any composite product based on milk, sorghum and legume for formulation of infant food (Desikachar 1983).

On dehulling an edible fraction of sorghum is removed as regarding protein but the digestibility of the grain is improved. But dehulling did not appear to have uniform influence on digestibility values of the sorghum products but, since only one variety of sorghum grain was used for the present study, no definite conclusion is possible from the results. In grains where polyphenol contents are high, dehulling will play a more important role on digestibility. Chibber et al (1980) in a study have shown that when high tannin sorghum was subjected to sequential dehulling (0-37%) nitrogen solubilised by pepsin increased from 22-71%.

Of the two fermented products dosa and idli, idli seems to have a better nutritive value than dosa. NPU of idli was significantly higher than dosa, though TD, DE and DMD of both dosa and idli were similar. The in vitro starch digestibility of dosa was significantly higher than idli. Traditionally both dosa and idli are prepared with a cereal-pulse combination. The nutritive value of a sorghum-pulse fermented product could be expected to have a better nutritive value. Sorghum dosa has been found to have good consumer acceptance (Raghavendra Rao et al 1978). Studies by Eggum et al (1983) and

Au and Fields (1981), suggest that fermentation could improve the nutritive value of a sorghum diet. The process of fermentation is inexpensive, does not require sophisticated equipment and consumes little energy and these are important points to consider in the utilization of sorghum.

CHAPTER VI

SUMMARY

Sorghum is the fifth most important cereal crop in the world in terms of production and is grown mostly in Africa, Asia and other semi arid tropical regions. It is the principal source of calories and provides a major portion of protein in the diets of the millions of people living in the SATs. However the optimum utilization of this rich store of nutrients present in sorghum grain, is complicated by various factors.

This study was taken up with the objective of studying the effect of processing on the protein and energy availability of grain sorghum.

Sorghum grain was subjected to primary processing, that is, dehulling by traditional and mechanical method. The common traditional dehulling method practised in Andhra Pradesh was followed. The PRL mini dehuller was used for mechanical dehulling.

The dehulled grains were analyzed for proximate and amino acid composition, *in vitro* digestibility, by enzymatic assay (protein digestibility by porcine pepsin and carbohydrate digestibility by α-amylase) and bioavailability studies by rat feeding trials. Statistical analysis was done to find the least significant difference at 5% level and correlation coefficients of various parameters were determined

It was found that on dehulling the protein, fat, ash and fibre levels were reduced significantly and starch levels were significantly increased. Between the dehulling methods it was observed that when values were expressed on a percent basis there was no significant differences in protein, fibre and starch values, and ash and fat levels in traditionally dehulled flour, were significantly lower. But when values were expressed in terms of yield it was seen that machanically dehulled flour had significantly higher levels of protein and starch. Mechanical dehulling was also more efficient in removing the fibre.

Lysine was the amino acid most affected on dehulling. On traditional dehulling the loss was 21% and a 16.5% loss was observed on mechanical dehulling. The other amino acids were not affected to any great extent.

In vitro starch digestibility showed a significant increase on dehulling and mechanical dehulling had a slightly higher starch digestibility than traditional dehulling though this increase was not significant. *In vitro* protein digestibility also showed a significant increase on dehulling. The traditionally dehulled flour had a higher protein digestibility value than machanically dehulled flour but again this increase was not significant.

Bioavailability studies with whole and dehulled grain indicated that, whole grain diet when fed to rats resulted in higher NPU values and increased weight gain, than dehulled grain diets, The true protein digestibility, digestible energy and dry matter digestibility values, however were higher in the dehulled grain diets. There was no significant difference in NPU or digestibility values between the traditionally and mechanically dehulled grain diets.

Based on these findings further study was carried out with various sorghum products. Whole and mechanically dehulled sorghum grain only were used in the preparation of the products as mechanically and traditionally dehulled grain did not display any marked differences in *in vitro* and *in vivo* assays. Whole grain and dehulled grain products used in the study were as follows.

Grain products		Flour products	
whole	dehulled	whole	dehulled
Parched	Boiled	Roti	Roti
Popped		Dosa	Dosa
Parboiled		Idli	Idli
Malted		Biscuit	Biscuit
Germinated			
Boiled			

All the products were again analyzed as for whole and dehulled grain previously (proximate analysis, amino acid composition, <u>in vitro</u> assay and bioavailability studies).

Differences were observed in the proximate composition of the sorghum products. Protein, fat and fibre contents decreased in a number of products. Germination resulted in a slight increase in protein content but it was not significant. Starch content of the products were low when compared to untreated grain, fermented products had the lowest starch content. Starch contents of most dehulled grain products were significantly higher than whole grain products.

In the sorghum products, again, lysine was the amino acid most affected. A 28% decrease was observed on popping and 39% in baking (biscuits). In the other treatments the loss ranged from 4%-20%. Methionine + cystine values were affected in dosa where about 11-20% loss was observed, and in biscuits the loss was 16%.

Highest IVSD was observed for fermented products. Boiled, malted and germinated sorghum had the lowest IVSD. All other products had digestibility values between these two extremes. The IVPD decreased significantly in most sorghum products, except in fermentation where IVPD was similar to untreated grain. Malted and germinated sorghum had IVPD significantly higher than all the other products and unprocessed grain. IVPD and TD was found to have a significant positive correlation.

In bioavailability studies it was noticed that most whole grain products gave higher NPU values, but dehulled products had higher digestibility values. Correlation coefficients indicated that NPU and TD did not have any significant correlation. NPU was positively correlated with DE and DMD. Weight gain was also more in most whole grain products except in popped and parched sorghum where weight gain was low. Biscuits and dosa prepared from dehulled grain failed to maintain growth in rats. The food intake of these rats were also low when compared to the other groups. The reason for low food consumption was not understood. All dehulled products had low NPU, though values were not significantly lower than the untreated dehulled grain except in case of dosa and biscuit prepared from dehulled grain where it was significantly lower. This was probably due to the high temperature that was used while preparing the products. Significant positive correlation was observed between NPU and lysine levels.

When the sorghum products were ranked and the over all ranking was considered, it was noticed that roti,prepared from whole and dehulled grain, malted and germinated grain, and idli prepared from dehulled grain appeared to have good protein and energy availability. Dehulled boiled grain also ranked good when all the bioavailability parameters were considered. Biscuit, dosa, popped, par boiled and parched grain either showed fair or poor protein and energy availability. The data obtained from the present study indicates that more work is required along these lines to enable the identification of better processing methods. Foods prepared with malted and germinated sorghum can be expected to have a better nutrient availability. There are only a few studies conducted on human subjects in this field and the results obtained thereof are interesting as well as challenging. More studies conducted on humans using traditional and novel processing methods will be useful. Also the identification of suitable sorghum-pulse combination with better processing method is most desirable at the present times.

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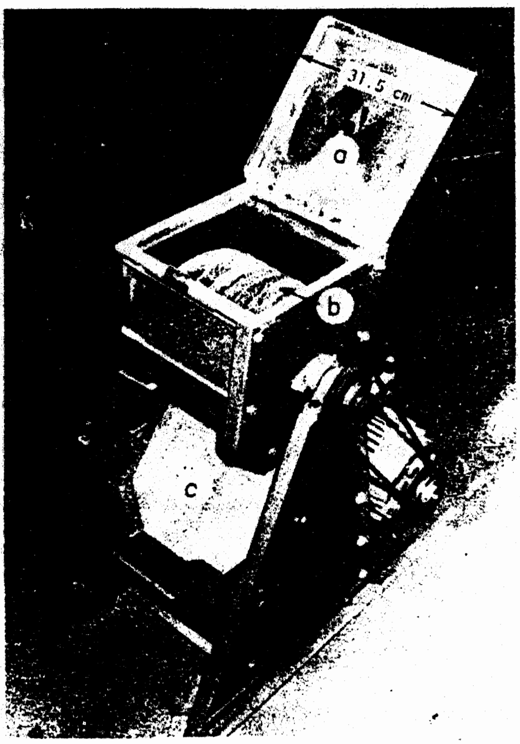
APPENDIX - I

P.R.L. 'MINI' DEHULLER

The P.R.L. 'MINI' DEHULLER was developed to fill the need for a small batch-type machine in rural communities. It was understood that people in these communities preferred to have their own grain processed, thereby retaining their own dehulled grain and the bran fraction, if desired. Since its development, research centres have found a need for a simple dehuller of this size to help stimulate the production and use of locally grown cereals. Commercial milling establishments also are showing interest in using this size of machine to provide local consumer service (Figure 11).

The P.R.L. 'Mini' dehuller uses the same basic principle as large, abrasive-type commercial machines in milling establishments. That is, a series of abrasive stones are fixed on a shaft, mounted in a case, rotated in a bed of grain.

Inexpensive resinoid steel cut-off disks or carborundum stones provide the abrasive effect. The disks are made of aluminium oxide abrasive, bonded by plastic into every thin, light, strong sections, that can be rotated safely at speeds of 6400 r.p.m. Eight disks are mounted between spacers on a shaft, with the end disks canted 8^{o}.



a - the cover plate
b - the disks or stones that rotate
c - the emptying chute

Figure 11: The PRL mini dehuller

The canted disks provide continual mixing and additional abrasive contact area for dehulling. When carborundum stones are required the canted disks are retained. However, the 6 disks in the middle are replaced by only 4 of the stones. This assembly is mounted in a case with a hinged top, where the grain to be dehulled is placed. Dehulling is performed by rotating the shaft assembly at a selected speed for a desired time. To remove the contents the case is rotated to the dumping position and the hinged top is unlatched. The mixture of dehulled grain and bran flows out by way of a chute into a collection bucket.

The dehuller operates on a maximum load of 7 kgs. and is useful in laboratory situations or in a village setting where it can perform service functions.

APPENDIX - II

Details concerning the preparation of sorghum products.

Parching: Whole sorghum grain was roasted in a hot iron vessel (110°C) for 2.5 minutes, (or till the desired aroma developed) with constant stirring.

Popping: Sorghum was popped by briskly agitating the grains in a preheated vessel (215°C) for 2.5 minutes.

Parboiling: Whole sorghum gain was soaked in water for 24 hours. The water was drained off andthe grain was steamed for $1\frac{1}{2}$ hours. The grain was sundried, powdered and stored.

Malting: Sorghum gains were soaked in water for 24 hours Then they were spread out on damp jute bag and kept covered for 48 hours (till the sprout length was approximately 2.5 cm). The vegetative portions were removed. The grains were toasted till the desired aroma developed.

Germinating: Sorghum grains were soaked in water for 24 hours and germinated as for malting. The germinated grain was then sundried powdered and stored.

Recipes: Roti, dosa, idli, biscuit and boiled sorghum was prepared with whole and dehulled grain and flour according to the recipes published in 'A variety of sorghum recipes', Colleges of Home Science, Department of Foods and Nutrition, Andhra Pradesh Agricultural University, Hyderabad, with slight variation as all sorghum food products were prepared with sorghum grain alone no other cereal or pulse was used in combination. The amount of fat used in baking biscuits was adjusted to enable preparation of isocalorie diets for the experimental animals.

APPENDIX III

Estimation of Total Starch

Reagents:

2 M Acetate buffer pH 4.8.

Glucoamylase enzyme (Sigma)

5% Phenol

96% Sulphuric acid

Dextraglucose

Procedure:

75 mg flour was wetted with 10 ml distilled water and autoclaved for $1^{1}/2$ hours at 19 lb pressure (1.5 kg/cm^2). After cooling 1 ml of 2M acetate buffer pH 4.8 and 25 mg of glucoamylase was added and volume made up to 25 ml. The reaction mixture was incubated in a water bath at 55°C for 2 hours then cooled and volume was made up to 250 ml. After appropriate dilution 1 ml of aliquot was treated with 1 ml 5% phenol and 5 ml 96% sulphuric acid. The mixture was kept in a water bath for 1/2 hour for colour development and the resultant colour was read at 490 nm. An appropriate standard was run simultaneously with dextraglucose and a calibration curve was used to convert optical density to mgs of glucose. After correcting with dilution factor the percent glucose was multiplied with 0.9 to give starch percent.

In vitro Digestibility of Protein

(Ref. Axtell *et al* 1981)

Reagents:

0.1 M Phosphate buffer pH 2.0

Porcine pepsin (Sigma)

Procedure:

200 mg of sample was suspended in 100 ml solution of pepsin (0.5 mg/ml) in 0.1 M phosphate buffer pH 2.0 and the mixture was incubated at 37°C for 2 hours. Appropriate blank containing pepsin only was run simultaneously. After 2 hours of incubation the suspension was centrifuged and the supernatant was analyzed for solubilized nitrogen. The digestibility value was calculated by dividing the supernatant nitrogen by total nitrogen in the 200 mg sample and multiplying by 100.

In vitro Digestibility of Starch

(Ref. Kon *et al* 1971)

Reagents

Soluble starch

0.1 M Sodium phosphate buffer pH 7.0.

0.05 M Sodium phosphate buffer pH 7.0.

α-Amylase (porcine pancreatic - Sigma)

Dinitrosalicylic acid reagent (DNSA).

Maltose.

Procedure:

2 ml of the sample slurry containing approximately 1% starch was taken to this 3 ml of water and 5 ml of 0.1 M sodium phosphate buffer pH 7.0 were added. After incubation at 37°C for 15 minutes in a water bath, 5 ml of porcine pancreatic α-amylase prepared as 1 mg/ml in 0.05 M sodium phosphate buffer pH 7.0 was added and incubated for 2 hours. Standard was prepared with 1% solution of soluble starch.

At the end of 2 hours, 1 ml of the reaction mixture was added to 2 ml of DNSA and heated in a boiling water bath for 5 minutes. After cooling the reaction mixture was diluted with 20 ml water and the colour developed measured at 540 nm.

A calibration curve using maltose was used to convert optical density readings to mgs of maltose.

VITA

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