NUTRITIONAL EVALUATION OF SORGHUM AS AFFECTED BY GERMINATION WITH MAIN REFERENCE TO DIETARY BULK AND PROTEIN QUALITY

BY

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A THESIS PRESENTED FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY IN THE
SOKOINE UNIVERSITY OF AGRICULTURE-MOROGORO-TANZANIA

NOVEMBER 1984

DECLARATION

I declare that this thesis is based on my work and the material has not been submitted to any other university for any award.

DEDICATION

This thesis is dedicated to:

1. My beloved parents Clemence and Lucia Mosha.

2. My late wife Lilian Irmina Mosha and late daughter Theresia Ndewerelia who died while I was half way through the study.

3. My children: Godfrey, Gloria and Eden-Carol who bravely endured my long absence from them while working on the thesis.

ABSTRACT

The nutritional value of sorghum as affected by germination and different dehulling techniques was studied with emphasis on protein quality, dietary bulk and food intake. Two low-tannin and two high-tannin varieties were investigated.

Nutrient content was affected by germination: minor changes occurred in proximate composition, except for a significant decrease in oil in all varieties. Thiamine, riboflavin and niacin content increased. Lysine increased in all varieties and the other essential amino acids increased marginally. Dietary fibre was unaffected. Tannin content decreased significantly.

Traditional and abrasive dehulling decreased the amount of protein, oil, dietary fibre, minerals, tannins and phytic-phosphorous.

Nutrient availability measured in vitro: protein digestibility was significantly higher in the low-tannin varieties. Germination and dehulling increased digestibility in all varieties. Cooking reduced protein digestibility in the high-tannin varieties and significantly more than in the low-tannin cultivars. Iron availability was low in all varieties and increased only in one high-tannin variety after germination.

Nutrient availability measured in vivo by rat-bio-assay: protein digestibility was high in low-tannin cultivars but low in high-tannin varieties. Germination increased digestibility only in one high-tannin variety. Biological values were higher in the high-tannin varieties. BV and NPU were not affected by germination. In vivo iron availability was higher in the low-tannin varieties and was increased by germination in only one of the high-tannin varieties.

Zinc availability was low and was unaffected by germination and tannin content.

Dietary bulk and food intake: When preparing weaning gruels, three times as much germinated flour of the low-tannin varieties, as compared to ungerminated, could be mixed into the same volume, while maintaining the same consistency of the gruel. Germinated flour of high-tannin varieties did not have this effect. Addition of 5% germinated low-tannin sorghum flour (enzyme-rich) to thick ungerminated gruels reduced the viscosity to acceptable weaning food consistency. This method of reducing dietary bulk of weaning food was accepted and used by mothers at village level. Food intake by 12-48 months old preschool children was significantly higher for bulk-reduced low viscosity gruel with 20% solids, compared to untreated gruel.

It was concluded that sorghum nutrient content is comparable to other cereals except for the high tannin content. Germination generally improves nutritional value through increased lysine, better protein digestibility and reduction of antinutritional factors, mainly tannins. The use of bulk-reduced high nutrient density weaning foods could eventually improve the nutritional status of young children.

Key words: Sorghum-germination, milling, nutrient content and availability, dietary bulk, weaning food intake.

ACKNOWLEDGEMENTS

I sincerely thank all the staff of the Tanzania Food and Nutrition Centre (TFNC) who in any way helped in laboratory and field work. In particular, I thank Dr. T.N. Maletnlema, the Managing Director, who allowed me time to undertake the study and his encouragement and learned guidance.

I thank all staff of collaborating institutions, who helped with technical support and research facilities, namely:

1. The University of Göteborg, Sweden.
   Department of Medical Biochemistry.
2. University of Uppsala, Sweden.
   Institute of Nutrition. Special thanks to Professor L. Hambraeus, Maivor and Sten-Åke Liedén.
3. The Vitamin Research Institute, Bergen, Norway, especially Einar Lied.
4. The Director and Sorghum Programme Staff of the Agricultural Research Institute in Ilonga Kilosa, Tanzania for providing the improved sorghum varieties.
5. Other institutions include the University of Lund (Sweden), University of Oslo (Norway), the National Institute of Animal Science and the Carlsberg Research Centre, both in Copenhagen-Denmark.
6. The University of Dar-es-Salaam and the Sokoine Unversity of Agriculture in Morogoro where the study was registered and offered academic and administrative services.

My sincere appreciation to Ulf Svanberg of Göteborg University as my overseas supervisor. He meticulously guided and encouraged me throughout the study and read the manuscript with very constructive critisism. The same applies to Dr. A. Haq of the Sokoine University of Agriculture in Morogoro-Tanzania.

Last but not least, I profoundly thank our secretary at TFNC, Mrs Solomon for typing the manuscript, Ingela Loubier at University of Göteborg and Inger Winkler at University of Uppsala for word processing of the final manuscript.

Special thanks go to the International Seminar and staff at the University of Uppsala who granted a fellowship for undertaking the study.

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CHAPTER I

1. INTRODUCTION

Sorghum (bicolor L. Moench) is the third most important cereal in the world in terms of production and use for food, especially in the Semi-arid Tropics (SAT) (Hulse et al. 1980a). The crop is drought resistant and grows well even in poor rainfall and low fertility soils (Suvakumar and Virman 1982). It is therefore a useful famine relief crop in drought prone areas, world wide including Tanzania (Brooke 1967 and Anon 1984) and thus offers a potential solution to the current world food shortage especially in developing countries (Rachie 1969, Brews 1980).

Sorghum grain is a staple food for a sizeable part of the population in tropical Africa, Asia and South America. In Tanzania it provides about 20% of the total cereal energy intake. It is also used as animal feed in North America and other developed countries (Rooney 1980). The plant is used as a source of sugar in some sweet stem varieties. The forage is a highly nutritive feed for livestock. The stover is also used for building huts, making mats and for fuel. Industrially sorghum and its products has many uses including starch, glue, beer and alcohol manufacture (Hulse et al. 1980b).

In human nutrition, sorghum grain, like other cereals, provides mainly energy, some protein and minerals. Although the utilization of these nutrients by human beings could be adversely affected in some varieties, it seems that the Protein Energy Malnutrition (PEM) problem in sorghum eating areas is primarily caused by a shortage of food in general. This is mainly because in some areas, sorghum is considered as a famine relief crop and the production tends to be too small in situations when drought has spoiled the growth of other staples such as maize. Therefore, it is generally found that in popoulations with nutritional problems especially young children (the under-fives), expectant and lactating mothers: sorghum is used as a staple food with other food items (Sai 1969 and Kloth 1978). Usually the purchasing power of the affected population is also low and the food available is inevitably too little to meet the needs of the family (Berg 1973, Jonsson 1977, Habicht 1983, Bantje and Yambi 1983).

The major nutritional problem in most sorghum eating areas as revealed in the aforementioned references, is Protein Energy Malnutrition (PEM). This problem affects about half the preschool children, causes high child mortality, morbidity and brain underdevelopment (Siddique and Abengowe 1984, Dobbing 1984, and McGregor 1984).

Another reason for low intake is related to dietary bulk. Starchy food items, especially those prepared as gruels, need to be diluted with a big amount of water to have a consistency that is appropriate for child feeding and hence the prepared food has a low nutrient density. This means that small children in particular, cannot eat enough to cover their needs of nutrients especially if the number of meals per day is low.

Nutritional anaemia together with PEM, are also common in Tanzania among all age groups, with preschool children and pregnant mothers being most affected (Tanzania Food and Nutrition Centre 1980). The iron deficiency state seems to arise from poor bioavailability of the dietary iron, and increased iron losses due to diseases and parasites (Maletnlema 1977, Kimati 1979, Crompton and Nesheim 1984).

Another important aspect of sorghum nutritive value is its supply of the B group of vitamins. Sorghum is likely to be a better vitamin B source than other starchy staples particularly if the grain is used in the form of malt.

However, some sorghum varieties present problems which must be overcome. These include the problem of inadequate decortication to remove the bran and produce acceptable milled products. The bran not only contains some nutrients which are lost during decortication but also primarily contains antinutritional factors such as polyphenols including tannins and phytates : all constituents which affect nutrient availability. Wide application of traditional technologies in sorghum processing and product preparation can, however, increase the quality of sorghum products and thus improve the nutritional status of the population. Such traditional technologies which are available and accepted down to the village and household level are mortar and pestle milling, stone grinding, germination and fermentation.

The present study concentrated on sorghum grain and some products in both ungerminated and germinated forms, using two local varieties and two recent improved varieties. The background information explored sorghum grain production and trends over the past two decades in the world and Africa. Particular treatment was given to production in Tanzania, processing, products and nutritional status in sorghum staple areas.

The literature review section was approached with emphasis on reviews and recent published material due to the wide and varied nature of the subject. Detailed reviews are given on grain sorghum germination and its effects on preparation of products, dietary bulk, protein quality and digestibility: mineral bioavailability and antinutritional factors. The main general conclusions were used to guide the investigations that were done.

Some characteristics of the subjects and materials are given along with experimental procedures for the topics under study including sensory evaluation. The results are presented and discussed separately. Field application of the major findings of the investigation, involving reduction of dietary bulk by using germinated flour ("Power Flour"), and food intake at village and household level are presented. This was done to take our findings to grass root level in an attempt to solve the problem of childhood malnutrition using locally available resources and know-how. Finally, general conclusions are drawn addressing the whole topic. Recommendations are made on the application of the findings and more research and development needed to further elucidate some aspects of the topic.

1.1 Objectives of the study

(I) To evaluate the effect of the following processing techniques: germination along with traditional milling (mortar and pestle) and abrasive milling on the nutritional value of sorghum with emphasis on:

a) dietary bulk aspects
b) protein quality and digestibility
c) iron and zinc availability
d) some vitamins
e) antinutritional factors.

(II) To test acceptability of weaning sorghum products on adults and preschool children at village level.

1.2 Hypothesis

(a) Germination and processing of sorghum might reduce dietary bulk, positively affect protein quality and make some nutrients more available.

(b) Modified germination techniques might be accepted at household level and be used to make products for weaning and adult uses.

CHAPTER II

2. BACKGROUND INFORMATION

2.1 Nomenclature of Sorghum

Hulse *et al*. (1980c) in their comprehensive work on sorghum indicate that there are many vernacular names given to the crop in Asia and Africa and among scientists there is some confusion with millets and corn (House 1980). The botanical name used in this thesis is *Sorghum bicolor L. Moench* for this is the current accepted term. However *Sorghum Vulgare* is also used in French publications.

2.2 History

Historically various investigators differ on the domestication of sorghum (de Wet *et al*. 1971). According to House (1980) who has the most comprehensive review, sorghum seems to have originated in Tropical Africa, probably in Ethiopia as the genus *Sorghum*, of the species, bicolor, which is a member of the grass family, Gramineae.

From Africa, through trade routes the grain spread to the Middle East, Asia and Europe Before Christ (B.C.). The spread in Africa seems to have followed the migration of tribes into West, East and into Southern Africa (Doggett 1970).

Sorghum was first introduced into South America in the mid 19th century and it has since developed as a major cereal (House 1980). Among the cultivated sorghums, the races Bicolor, Guinea Caudatum, Kaffir and Dura with their hybrids dominate world production. It appears that Tanzania has a combination of all these races along with several wild sorghum varieties.

2.3 Research and Development

A comprehensive review on sorghum production and utilization was produced by Wall and Ross (1970). The bibliography on the world literature of sorghum compiled by Sangameswaran and Gopinath (1976) covers mostly preharvest aspects, while post harvest related nutritional attributes are covered sketchily. The world collection of sorghum at ICRISAT, India, had 21,264 accessions in 1981 (Mangesha and Prasada Rao 1982). Tanzania has so far collected 305 local varieties, on top of 4 improved varieties namely, "Lulu Short and Tall", "Serena", "Dobbs" and "Tumaini", while other promising varieties including hybrids are under development (Mukuru 1979).

Local white (low tannin) varieties such as Mbangala are most common along the coast, Msumbiji dominates in the south of the country, while in central Tanzania Langilanga and Lugugu are the most widely grown varieties. Among the brown types (high-tannin) Udo is most common in the central part of the country. Breeding and agronomic research has been done in the USA at Texas A and M University (Miller 1982a) and it is still in progress: at ICRISAT, India (ICRISAT 1980), Serere in Uganda for East Africa (Mukuru 1977) and the Kilosa National Cereals Improvement Programme in Tanzania (Ministry of Agriculture 1983).

Serious work on the food and nutritional qualities of sorghum has only recently been undertaken in the USA in Texas (Rooney et al. 1970 and 1980, Rooney and Murty 1982) while Purdue University has been concentrating on chemical and biochemical attributes (Price et al. 1979, Butler 1982 and Axtell et al. 1982).

The recent symposium on "Sorghum in the Eighties" and "Sorghum Grain Quality" held at ICRISAT in India (ICRISAT 1982) brought together all aspects of sorghum from production and processing to nutrient availability to humans and animals. Sorghum genetics, agronomy, diseases, food quality and utilization, socioeconomic aspects, antinutritional factors and conventional food products were highlighted during the symposium. Initially it appears that local varieties, though low in yield, have physical and chemical characteristics which make them, more acceptable to humans than improved types.

2.4 Sorghum Production

The world and selected subregional production of sorghum is summarised in Table 1.

Geographical distribution of sorghum is largely, confined to tropical and subtropical climatic conditions, though recently high altitude and cold climate varieties have been developed (Miller 1982). According to FAO estimates (1982) as indicated in Table 1, between 1964 and 1982, the world sorghum harvested area, averaged 44.2 million hectares, increasing from 36.7 million to 47.5 million hectares. This was an increase of 29%. Production over the same period rose from 38.8 (1964-68) million tons to 70.6 in 1982: an increase of 82%. The increment occured mainly in the developed world due to a rise in yields per hectare owing to high yielding improved varieties and hybrids mainly in North America (Doggett 1982). However yields per hectare in developing semiarid countries in Africa and Asia improved a little or remained static (Leng 1982). North and Central America were the largest producers with 28.0 million tons in 1981-82 (an increase of 52% from 1964 to 1982). This was followed by Asia with 20.0 million tons (1981-82). Africa in 1981-82 produced 11.4 million tons from 15.5 million hectares, an increase of 42% over 1964-68 arising mainly from a 52% increase in hectarage over the period especially in West and East Africa.

All the regions in Tanzania grow sorghum as shown in Table 2. Shinyanga was the highest producer averaging 142 thousand tons per year

Table 1 Sorghum - World and Selected Regional Production 1964 - 1982

	Area Harvested (1000 Hectares)				Production (1000 Metric tons)			
	1964-1968	1969-1971	1978-1980	1981-1982	1964-1968	1969-1971	1978-1980	1981-1982
World	36,675	45,915	46,513	47,513	38,781	54,213	62,605	70,557
North and Central America	6,128	7,244	7,212	7,707	18,497	22,419	22,801	28,040
Asia	18,895	22,947	21,568	20,682	9,812	17,381	21,165	19,954
Africa	10,218	13,066	14,482	15,538	8,109	9,094	10,230	11,485
South America	1,103	2,097	2,517	2,942	1,756	4,052	6,735	9,101
Oceania	183	375	478	658	282	761	873	1,266
Europe	102	143	182	164	262	444	689	611
USSR	50	43	86	112	57	62	112	100

Source: FAO Production Year Book Volume 23 (1969), Volume 34 (1980) and Volume 36 (1982).

Table 2 Regional Sorghum Production 1974/75 to 1980/81 (Thousand Tons)

	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	1980/81
Dodoma	47.5	50.1	45.2	131.6	138.1	148.3	65.4
Arusha	12.7	13.4	8.7	12.0	29.6	39.0	34.3
Kilimanjaro	n.a.	0.1	0.5	0.7	1.4	0.5	5.0
Tanga	5.8	5.8	6.4	8.2	23.9	26.5	1.4
Morogoro	10.0	13.0	23.8	15.0	53.1	42.6	120.9
Coast	5.7	8.1	2.2	42.8	42.8	n.a.	11.0
Dar es Salaam	0.3	0.5	0.2	0.1	9.4	n.a.	n.a.
Lindi	20.0	25.0	31.2	25.9	14.4	19.3	14.0
Mtwara	41.3	50.2	14.8	61.6	32.0	48.8	87.4
Ruvuma	0.2	11.9	2.4	4.0	3.0	13.6	0.2
Iringa	0.3	0.2	0.1	0.4	2.1	4.0	23.6
Mbeya	2.4	2.7	1.0	1.8	9.4	10.3	11.5
Singida	42.6	41.0	40.0	63.3	91.7	110.5	116.6
Tabora	9.6	24.3	101.0	62.5	83.5	61.8	49.0
Rukwa	n.a.	0.6	5.1	5.5	6.9	12.1	3.0
Kigoma	13.3	5.3	5.3	8.5	6.8	2.8	6.2
Shinyanga	49.6	137.1	181.6	118.2	204.5	94.7	208.8
Kagera	12.3	6.7	13.3	15.3	8.5	7.6	0.2
Mwanza	18.3	14.2	26.1	26.5	37.3	230.7	55.3
Mara	12.3	12.3	12.3	9.7	24.9	49.0	25.1
Tanzania (Main Land)	304.2	430.5	521.7	613.6	823.3	922.1	838.9

Source: Tanzania Food and Nutrition Centre 1982. n.a. - Not available.

between 1974 and 1981. The drier regions of Dodoma, Singida, Tabora and the slightly less dry regions of Mwanza, Shinyanga, Mara, Lindi and Mtwara were the major producers of sorghum.

Observations from Table 2 should be taken cautiously since the method of agricultural statistics collection in the country is subject to inaccuracy and variation. Agricultural extension officers in the districts and in villages estimate hectarage and yields and send the data to the central government. This means that the figures are more or less estimates, since for accuracy, actual areas and yields should have been measured and weighed respectively.

The trend over the period indicates fluctuations within each region from year to year and this was mainly due to adverse weather conditions between 1974 and 1976 and favourable weather in the late seventies and early eighties. Over the period under consideration (1974-1981) national production of sorghum increased from 304 to a high 922 thousand tons in 1979/80 which was an increase of about three times. The rise in production was mainly due to increased hectarage and a more extensive use of improved high yielding sorghum varieties such as "Serena" and "Lulu". A sustained campaign by government to promote the crop as a famine relief crop after periods of drought and food shortage, also contributed substantially (Mosha et al. 1977). In addition, official price incentives seem to have worked since the price of sorghum increased from 0.75 Tanzanian shillings per kilo in the 1975/76 season to 1.00 shilling in 1977/78.

2.5 Sorghum in Human Nutrition

The grain composition differs with variety and environmental conditions (Srikantia 1976) but averages 80-82% endosperm, 6-8% bran and 10-12% germ. Nutritional energy is contributed by the carbohydrate fraction, mainly the endosperm with about 25% amylose and 75% amylopectin content in most widely grown varieties (Rooney and Sullins 1977). The germ also contributes. Protein content averages 10% and provides the bulk of vegetable protein for sorghum consuming populations. The most limiting amino acid in sorghum proteins is lysine (Food and Agricultural Organization 1970). However high protein and lysine varieties recently developed are under promotion (Singh and Axtell 1973), but their floury endosperm affects the final quality of the products. Mineral content is comparable with other cereals but iron content is slightly higher (Hulse et al. 1980a), while vitamin content, apart from the B group of vitamins is low. The oil content averages 3.5% (Price and Parsons 1975).

2.5.1 The importance of Sorghum in Relation to the other Major Staple Cereals

As shown in Table 3, sorghum was the second most important cereal crop after maize in Tanzania averaging 0.6 million tons per annum between 1974/75 and 1979/80. It is also interesting to note that the rate of increase in production for sorghum was double that of maize while apart from millet, wheat and paddy production actually decreased over the period (Mosha 1982).

Using a conversion factor of 0.8 (the balance assumed to be losses in handling and seed use) and assuming that the population averaged about 17 million people, sorghum alone provided about 270 kcal/caput/day yearly, between 1974/75 and 1979/80, thus under-scoring the importance of sorghum in the national diet. The figure is only a national aggregate, but in dry areas sorghum and millets could have provided an estimated 80% of all dietary energy over most of the year. At the national level sorghum food energy production increased from 136 kcal/caput/day in 1974/75 to 413 kcal/caput/day in 1979/80, again emphasizing the rising importance of sorghum contribution to the average Tanzanian food situation (TFNC 1982).

Table 3 Production of Sorghum in Relation to the Major Cereals in Tanzania (1000 Metric Tons).

	1974/75	1975/76	1976/77	1977/78	1978/79	1979/80	Average
Maize	1,332.0	1,513.0	1,648.0	1,465.0	1,882.0	2,118.0	1,660.0
Paddy	285.8	373.4	365.7	387.3	449.2	282.5	357.3
Wheat	83.4	67.3	61.5	54.6	n.a.	52.4	63.8
Sorghum	304.2	430.5	521.7	613.6	823.3	922.1	602.6
Millets	146.3	131.9	220.5	309.1	459.4	n.a.	253.4

n.a. - Not available.

Source: Ministry of Agriculture - Planning, Statistics. Dar es Salaam. Tanzania.
Compiled by Tanzania Food and Nutrition Centre TFNC (1982).

2.5.2 Sorghum Milling

Sorghum like most other cereals has to be processed into edible products. It keeps better than maize under normal storage conditions (Mahibu 1984) because the small grains compact well and the testa is hard and smooth. Traditional methods for milling sorghum into flour and related products using the mortar and pestle and the grinding stone in Africa, Asia and Latin America, usually causes nutrient losses (Vogel and Graham 1979). Industrially, modified abrasive decorticators used usually for rice followed by hammer milling, achieve adequate bran free sorghum flour (Desikachar 1977). Extensive pilot plant studies on sorghum polishing using abrasive machines have indicated that some African flintly local varieties could easily be polished into acceptable products by an abrasive milling technique (Kapasi-Kakama 1977, Reichert 1982). The abrasive mill developed by the Canadian International Developement Research Centre (IDRC) is reportedly successful (Eastman 1980) and was used in this study. It appears that household and larger scale decortication is a major bottle neck in sorghum milling but serious efforts to solve the problem are under way (Reichert 1982, Munck et al. 1982), mainly developing abrasive milling techniques with air classification.

2.5.3 Sorghum Food Products other than Beverages

A wide variety of local products are made from sorghum and are widely consumed as prestigeous staples in parts of Africa and Asia (Muller 1970, Vogel and Graham 1979).

In summary, flour based products include stiff porridge "ugali" in East Africa (Mukuru 1982) or "To" in West Africa (Da et al. 1982) and the rest of the Sahel Zone. There are many variations but the porridge is often taken unfermented except in Botswana where "Bogobe" (local porridge), is fermented (Boling and Eisner 1982). Bread like products are also prepared and these include flat bread "chapati", Indian roti

(Murty and Subramamian 1982), Sudanese "Kisra" (Ejeta 1982), Ethiopian "Injera" (Gebrekidan et al. 1982) and Mexican "Tortillas" (Iruegas et al. 1982). Whole grain cooked like rice or semolina, puffed or flaked preparations are also taken as snacks or breakfast cereals.

2.5.4 Weaning Foods

A very important use of sorghum flour is the preparation of weaning gruels. The majority of the children in the semi-arid tropics are weaned using gruels which highly determine their nutritional fate. All the sorghum producing areas have varying names for the same product. Over most of East Africa, "Uji" is the most common term and it is usually unfermented and fed to children sometimes with little supplements such as milk, fruit juice or pounded oil seeds. In West Africa, it is mostly used fermented whereby among others "Ogi" is most common in Nigeria (Ankirele et al. 1967, and Banigo and Muller 1972a), while a similar product is common in Ghana (Muller 1970). "Togwa" in Tanzania or "Mahewu" in Southern Africa (Novellie 1982), are liquid consistency semifermented drinks which are also fed to young children

2.5.5 Composite Flours

Sorghum can be used mixed with other flours such as wheat, maize and root crops. Extensive work on composite flour bread and related baked products at the Tropical Products Institute in London (1970) and Sudan (Perten 1977), showed that wheat bread containing up to 20% sorghum flour did not differ significantly from wheat bread. However, large scale commercialization has yet to be realized.

2.5.6 Nutritional Status of Sorghum Staple Areas

From the aforementioned the nutritional status of most sorghum staple areas in the world, is not optimal and is characterized with high incidences of Protein Energy Malnutrition (PEM) especially in the Sahel Zone, the rest of Africa and Asia (Centre for Disease Control 1978 and Lotain 1984). In Tanzania, the situation is not very different especially among children as indicated in Table 4 which highlights PEM and nutritional anaemia.

Table 4. Frequency of Malnutrition in Tanzania among Children Attending Mother Child Health (MCH) Clinics in Major Sorghum Producing Regions (Average from January to June 1976-1979)

Region	Under weight %	Kwashiorkor and Marasmus %	Anaemia %
Singida	9.4	3.9	0.5
Dodoma	6.4	2.5	0.7
Coast	5.7	2.1	1.1
Mwanza	5.4	2.0	0.8
Shinyanga	5.3	2.4	1.1
Mara	4.7	2.1	1.0
Mtwara	4.2	1.9	0.8
Tabora	3.8	2.4	0.9
Lindi	3.4	2.3	0.8
Kigoma	2.6	2.5	0.3
Average	5.1	2.4	0.8
Tanzania (all mainland regions)	5.5	2.2	0.8

Source: Tanzania Food and Nutrition Centre Data Report (1982).

The data in Table 4 indicates that underweight among children attending MCH centres in the regions, varied from 2.6% in Kigoma to a high 9.4% in Singida region which is the biggest sorghum and millets consumer. The average of 5.1%, which was slightly below the 5.5% for the rest of the country. Kwashiorkor and marasmus varied from 1.9% in Mtwara to 5.9% again in Singida with an average of 2.4% among sorghum producers which was slightly higher than the national average of 2.2%. However the data was derived from children who visited the MCH Clinics, who were only a fraction of the total children population in the regions. Since the MCH services are fairly wide spread and visits are routine and fairly regular, the data gives a reasonable picture of the state of nutrition among the children.

Anaemia incidence did not vary much over most regions but it was wide spread, varying from 0.3% (Kigoma) to 1.1% in Coast and Shinyanga regions, with a national average of 0.8%. The anaemia problem is enhanced by parasites and diseases. It is therefore highly suggestive that the sorghum producing regions in Tanzania have nutritional problems among children as observed from MCH statistics. Major malnutrition underlying causes where sorghum dominates, are partly poor weaning food practices with high dietary bulk foods, low protein quality and mineral deficiency (Maletnlema 1977, Tanzania Food and Nutrition Centre 1980).

In retrospect, the high quantities of sorghum produced and consumed in most developing countries using various traditional technologies, sustain the lives of millions and determine their respective nutritional status. Associated problems require tackling so as to make wider use of sorghum and possibly alleviate the malnutrition problem especially among young children: hence the importance of the present study.

CHAPTER III

3. LITERATURE REVIEW

3.1 Dietary Bulk

This section reviews studies on dietary bulk as a limiting factor to food intake, looks at the magnitude of the problem, basic causes, previous attempts at solving it and potential solutions requiring more investigation.

The concept of dietary bulk is relatively recent among nutritionists and has been studied mainly in connection with weaning foods. Dietary bulk refers to the factors that make it difficult for an individual to consume enough food to meet daily nutrient requirements. Usually weaning foods in most developing countries are non-milk starchy based local staples such as cereal and root flours made into thin porridges with adequate feeding consistency, subsequently containing much water and big volume. This means that the nutrient density, that is nutrient per unit volume of food, is very low. Young children have high nutrient requirements in relation to body size. Their relatively small stomachs, make it impossible for the children to ingest enough nutrients especially if the number of feeds per day is low. If the amount of solids containing starch is raised to increase nutrient density, the final product is too thick and viscous for feeding the young. This high volume/viscosity character of a diet is referred to as "dietary bulk" and is considered a big problem in the etiology of malnutrition as it limits food intake especially among the young (Ljungqvist et al. 1981).

Historically, the literature reviewed indicates that dietary bulk as a limiting factor for nutrient intake in preschool children was first conceived and developed in Göteborg, Sweden by a group led by Mellander in 1976 and several basic publications have ensured from the group (Ljungqvist et al. 1981, Hellström et al. 1981, Mellander and Svanberg 1984, Svanberg et al. 1984a, Svanberg et al. 1984b).

Another group working at Dunn Laboratories in England has been under the leadership of Whitehead and they have concentrated on energy intake in Gambia (Whitehead et al. 1982, Paul et al. 1979, Black et al. 1983). The main findings confirm that the low energy per volume of food consumed limits nutrient intake. Recently work at the Central Food Technology Research Institute (CFTRI) in Mysore India has indicated that dietary bulk is a problem in cereal based weaning foods supplemented with legumenous flours whose viscosity is high, at as low as 10% solids (Brandtzaeg 1979, Desikachar 1980).

Recently, the work at Göteborg University on dietary bulk was continued in collaboration with the Tanzania Food and Nutrition Centre, details of which are given later in this thesis (Mosha and Svanberg 1983).

3.1.1 Factors Influencing Dietary Bulk

Carbohydrates especially starch, are the most important determinants of dietary bulk. Cereal starch contains granules of polymeric material which occurs in different sizes and shapes as demonstrated by the Fluorescence Michrochemical View technique (Fulcher and Wong 1980).

Solutions or dispersions of food particles such as flour has different rheological properties and usually behave as non-Newtonian fluids because of the diverse nature of their composition (Howling 1980), consequently they have high viscosity or consistency when prepared as weaning gruels (Church 1977). Beta-glucans which are highly viscous occur in sorghum (Earp et al. 1983).

On heating starch in water to boiling, it first gelatinizes at a characteristic temperature by swelling and solubilized amylose and amylopectin diffuse into the water and they cause an increase in viscosity. Upon cooling, the starch-paste starts to gel and the viscosity increases further. The gel then consists of swollen granules and soluble amylose which entraps unabsorbed water and links together intact starch granules into a three dimensional gel-like network upon cooling (Ott and Hester, 1965). Similar behaviour has been reported in sorghum gruels (Cagampang et al. 1982 and Akingbala et al. 1982).

Swelling is, however, not limited to starches alone in food gruels. Hermansson (1972) reporting on functional properties of proteins stated that protein denaturation and swelling was observed in whey and soy protein isolates and overall influences solubility, viscosity and gel formation due to protein-water interactions.

Dietary bulk properties are furthermore influenced in various ways by other food components usually used in food preparation such as salts, sugar, pentosans, pH, fat and surfactants.

On the effect of salts, the literature has conflicting reports but consistent within the same cultivars. Sodium chloride reduces the swelling and hence viscosity of potato starch but increases that of maize or wheat starch (Hellström et al. 1981).

Pentosans occur in cereal flours at a level of 2-3% and these are partly water soluble (Jelaca et al. 1971) and absorb much water in wheat flour dough.

The pH of most foods ranges between 4-7 and little variation occurs in viscosity when cooking in starch water systems, according to the literature reviewed. In West Africa some communities add temarind which is acidic to sorghum gruels, (Vogel and Graham 1979) but this often influences organoleptic properties rather than viscosity.

Fat retards starch gelatinization depending on the nature of the lipid used while polar lipids generally decrease consistency of cooked starch (Medcalf et al. 1968, Dearden 1980), but adding vegetable oil and fat have little effect on the gel formation of starch gruels.

3.1.2 Fibre and Dietary Bulk

Several definitions have been given for dietary fibre but a recent review by Eastwood and Passmore (1983) neatly sums up "dietary fibre as mainly polysaccharides, the indigestible components of plant cell wall". Recently, Kearns and Lowly (1984) reviewing the analytical methods used, physiological effects and importance of fibre in the diet reached a similar conclusion, but added phenolic compounds lignins and tannins. Maillard-reaction products have also been classified as dietary fibre (Soest 1984).

Although many benefits arising from dietary fibre are reported, for adults, such as slowing transit time in the upper gastronomic channel and allowing more thorough digestion and rapid movement in the colon (MacLean et al. 1983, Heaton 1983), these benefits have not been correlated with dietary bulk and dietary energy density. However, for infants a high dietary fibre diet may be disadvantageous in that it absorbs and binds much water and thus causes both a high dietary bulk and a high fecal bulk (Southgate 1973).

3.1.3 Dietary Bulk and Child Malnutrition

Studies on food intake among infants who were fed milk based formulae at different energy concentrations consumed more of the low energy formulae (Fomon et al. 1969, 1971 and 1975). A similar pattern was observed among low birth weight infants fed raw energy rich hind milk (Spencer et al. 1982), but the energy concentration, like in Fomons studies in 1969, did not affect the rate of weight gain and no satisfactory explanation was given in any of the cases. However it was obvious that physiologically, low energy density diets (high bulk) necessitated ingestion of larger volumes.

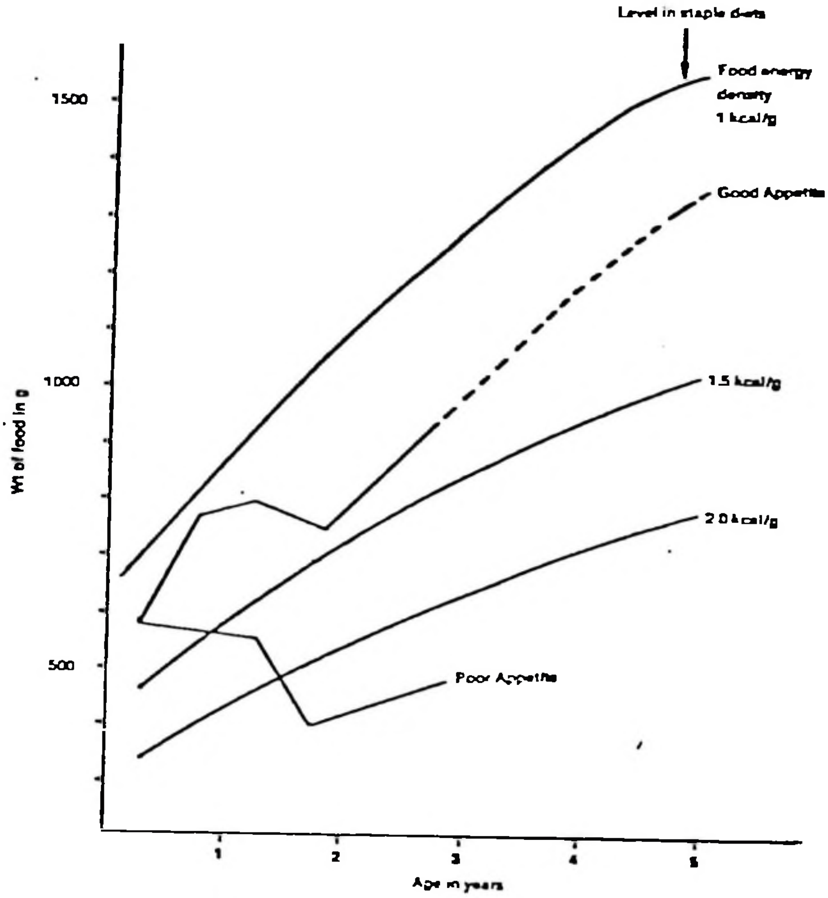

Fig. 1. Food intakes of children on traditional staple diet compared with amount of food with differing energy density (After Church 1977, extracted from Binns 1975 and Rutishauser and Frood (1973).

In some few intake studies, when children were given starch-rich staples ad libitum the consistent finding was of low over all energy intakes. Figure 1 after Church (1977) is based on data from two such studies. One from Uganda, with plantain as the staple (Rutishauser and Frood 1973) and the other from Papua New Guinea, with sweet potato as the staple (Binns 1975). Even with very good appetites these children had difficulties in eating enough food to cover their energy requirements. Similar results were obtained in a food intake study on Indian rural children (Jones and Pereira 1972), and Rutishauser (1974) on Ugandan preschool children.

3.1.4 Attempted and Potential Solutions to the Dietary Bulk Problem

Several attempts have been tried to solve the dietary bulk problem, and most have advantages and disadvantages as indicated in the following section.

(i) Extrusion

Extrusion cooking using different types of extruders at temperatures of above 200°C (Mercer et al. 1975), breaks down the starch complex and lowers its water binding capacity and viscosity as observed in sorghum grits extrusion (Conway et al. 1968 and Anderson et al. 1969). This has been applied in the production of high energy soy blend weaning foods based on cereals (Jansen et al. 1981). However this method is expensive and mainly applicable at industrial level.

(ii) Enzyme Treatment

Enzyme treatment with pure amylases also lowers viscosity (Karlsson and Svanberg 1982) as done in weaning food manufacture (Buffa 1969), but again this is mainly suitable for large scale production. At the household level, dietary bulk of starchy, thick weaning foods is reduced by the mother or who ever does the feeding by chewing the food (whereby the salivary amylase thins it) and introducing it into the child's mouth. This is practised with starchy staples in parts of Africa including Tanzania (Lema 1963) . However this practice is, inconvenient and unhygienic and could lead to the spread of communicable diseases.

(iii) Fermentation

Fermentation of cereal flour porridge breaks down the starch structure and reduces the water binding capacity of gruels as observed in sorghum "ogi" (Banigo and Muller 1972b). However the flavour of fermented cereal weaning foods though acceptable in West

Africa and Asia is not very common in East Africa especially in Tanzania. In East Africa cereal fermentation often usually ends up with alcoholic beverages (Novellie 1977 and 1982) rather than weaning foods of adequate energy density. The risk for growth of harmful microorganisms during the fermentation is also obvious though it improves the nutritional value of sorghum (Au and Fields 1981).

(iv) Use of additives

Another attempted solution is the addition of oils and fats or sugar which are energy concentrates (Rutishauser and Frood 1973). However, though the additives are desirable, they are relatively scarce and too expensive among poor rural communities. The amounts that can be added are also limited since too much oil or sugar may render the food unacceptable especially to the young.

(v) Germination

Germination is a natural process and is practised world wide at all levels down to the household especially for cereals and legumes (Hsu et al. 1973, Chen et al. 1975, Fordham et al. 1975, Chen et al. 1977, Wang and Fields 1978). It has nutritional beneficial effects such as improved digestibility and possibly better nutrient availability in some legumes (Kumar et al. 1976, El Mahdy 1982).

The physiology and biochemical changes taking place in germinating seeds are broad and have been widely studied and reviewed for millet and barley (Sheorain and Wagle 1973), wheat (Chittenden et al. 1978) and maize (Fujimaki et al. 1977). Sorghum has been studied widely in relation to the brewing industry (Novellie 1977, Watson and Novellie 1976, Novellie 1982 and Glennie 1983).

Relevant biochemical changes occuring which are related to dietary bulk include the activation of starch breaking enzymes (Ott and Hester 1965, Manners 1974, Jensen and Heltved 1982, Mundy 1982, Okon and Uwaifo 1984), which produce oligosaccharides and even simple sugars such as glucose (Sheorain and Wagle 1973, Fretzdorff et al. 1982). The amount of enzyme formed depends on the cultivar: low-tannin sorghum producing more enzyme activity at an early stage of germination than high-tannin types.

It is therefore apparent that germinated cereals when milled and made into gruels will swell less and produce less viscous products due to the partial breakdown of the starch component. At the same time the crude enzymes especially alpha-amylase so produced could be used under suitable circumstances to reduce the viscosity of thick gruels, thus offering a cheap, familiar simple solution to the dietary bulk problem right at the household level especially in weaning foods.

The food intake studies reviewed, yielded no report on the addition of naturally occuring crude enzymes from sorghum to tackle the dietary bulk problem in relation to weaning foods at village and household level. The present study was therefore undertaken, with the aim of formulating practical approaches towards solving the problem.

The first attempt to measure the effect of a bulk reduced diet in a food intake study on preschool children using germinated sorghum flour added in small amounts was reported recently (Svanberg et al. 1984a) as a follow up of our earlier findings (Mosha and Svanberg 1983). A sorghum-based weaning food was served as a porridge either as breakfast or supper during a 20 day period to 20 Ethiopian orphanage preschool children. When a small amount of germinated sorghum flour was added in the preparation of the porridge, 25% more of the weaning mixture could be used within the same volume and still having the same viscosity. The bulk-reduced porridge was then ingested in equal amounts compared to the ordinary porridge, which means that the nutrient intake on the bulk-reduced porridge was 25% higher.

In retrospect, the literature reviewed raises pertinent issues on dietary bulk. The swelling and high viscosity of starches is not consistent in all cereal starches, and differs in different sorghum varieties (Ejeta 1982). The effects of various additives such as protein sources, oils, fats, sugar or food quality chemicals which affect viscosity or texture as well as processes such as fermentation and germination were largely based on laboratory level studies involving model systems and flour from cereals other than sorghum.

3.2 Nutritional Value of Food Proteins

The nutrient contribution of food protein mainly depends on its quantity in the food, the quality of the protein and its availability (Eggum 1973). Protein quality is a function of mainly the essential amino acid content, balance and proportions as indicated in relevant reviews (Silano 1977, Hsu et al. 1978, Satterlee et al. 1979, Reed and James 1983).

Chemical assays of protein quality involves an analysis of the quantity of each essential amino acid and a comparison with the corresponding amino acid in a suitable reference protein or amino acid pattern. The amino acid that shows the lowest proportion compared to the reference is called the limiting amino acid, and the ratio obtained is the score. A provisional amino acid scoring pattern based on evaluation of human amino acid requirements was proposed in the 1973 joint FAO/WHO report on Energy and Protein Requirements. The amino acid score of a protein was calculated as follows:

$$\text{Amino Acid Score} = \frac{\text{(mg of amino acid in 1 g of test protein)}}{\text{(mg of amino acid in reference protein)}} \times 100.$$

Provided that the lowest score obtained for any of the essential amino acids is used (i.e. the most limiting amino acid), the score may be taken as a first approximation of the quality of the protein.

Amino acid scores derived from the limiting amino acid should be comparable to the biological value (BV) assayed in nitrogen balance studies in humans and animals. The significance for human nutrition, of values obtained from an animal bioassay procedure needs to be interpreted with caution. However, values obtained from rat bioassays have been shown to have a predictive significance in relation to human protein nutrition (Bressani et al. 1969).

The biological value (BV) is defined as the fraction of the absorbed nitrogen that is retained, whereas the net protein utilization (NPU) is a measure of the fraction of the intake nitrogen that is retained, i.e. an index inclusive of digestibility (D). A correlation between the amino acid score and NPU will therefore only be high when the digestibility is high.

3.2.1 Nutritional Value of Sorghum Proteins

The protein content in sorghum is reported to vary from 8-16% for normal and high lysine varieties respectively and is further influenced by the ecology and fertilizers (Myers and Asher 1982, Ajakaiye 1984). Soluble proteins of sorghum have been fractionated into prolamine (dominant), glutelin, globulin and albumin (Jambunathan and Mertz 1975, Taylor et al. 1984).

The protein quality of sorghum has reportedly been studied using the above mentioned approaches, but the work done is small compared to other cereals such as wheat, barley and corn. Studies reported fall into two classes: namely those based on white (low-tannin) and brown (high-tannin sorghum varieties (Axtell et al. 1982).

The amino acid pattern and content of normal sorghum is not very different from other cereals but sorghum protein is usually low in quality because it has a low lysine content which is the first limiting amino acid along with threonine and tryptophan (Silano 1977, Salukhe 1977, Guiragossian et al. 1978 and Jambunathan et al. 1983). Amino acid scores for lysine are reported to be about 35% in normal sorghums and up to 63% in high lysine sorghums which is slightly higher than reported for normal maize (Hulse et al. 1980a).

The presence of a relatively high concentration of leucine in sorghum has been suggested as a possible factor in the development of pellagra in a population group subsisting principally on sorghum (Gopalan and Srikantia 1960, Belvady et al. 1967, Carter and Carpenter 1981). Removal of bran and germ during decortication significantly decreases the lysine content, while changes in other essential amino acids due to milling are limited (Eggum et al. 1982).

Germination of sorghum grain has been shown to significantly increase the level of lysine in both normal and high lysine sorghum varieties (Wu and Wall 1980, Au and Fields 1981).

Data on biological value of sorghum proteins has been reported in nitrogen balance studies as well as in growth studies using mainly growing rats and chickens. Although the data is not directly applicable to humans, it may serve as a good guide or indicator (Nutritional evaluation of protein foods, Eds. Pellet and Young, 1980). Several studies have reported a significant correlation between lysine content in different sorghum varieties and biological value (BV) as well as weight gain in both rats and chickens (Singh and Axtell, 1973, Sikka and Johari 1979, Eggum et al. 1983, Featherston et al. 1975). These findings are reported for low-tannin sorghum genotypes. In high-tannin sorghum lines, however, there is an important interaction between tannin content and protein availability which is not usually found in mostof the other major cereals. Weight gain in rats and chickens were significantly reduced by increasing level of tannins from sorghums in the diet (Cummings and Axtell 1973).

In balance studies the protein digestibility was significantly reduced in high-tannin varieties fed to rats (Eggum and Christensen 1975) and laying hens (Muindi and Thomke 1981). The digestibility was furthermore reduced in cooked samples of high-tannin sorghum grain (Price et al. 1980, Eggum et al. 1983). Decorticating the sorghum grain usually means a loss of embryo and aleurone layer proteins which are rich in lysine and also a subsequent loss of tannins mainly from the testa. Decortication of sorghum had a positive effect on protein digestibility whereas the biological value (BV) was reduced due to the reduction in lysine content (Eggum et al 1982).

The effect of tannin on protein digestibility seems to be caused by a specific binding of tannin to proline residues in the protein and thus the prolamine fraction in sorghum proteins which are rich in proline but poor in lysine (Butler 1982). Nutritionally this binding leads to interesting effects. In rat trials Eggum and Christensen (1975) found that the protein digestibility was reduced but the biological value (BV) was incereased in tannin-rich varieties of sorghum. This is due to the selective binding of tannins to the low lysine prolamines which then become unavailable thus improving the amino acid composition of the proteins which are left for the rat to digest and absorb, finally resulting in an increase in BV. In recent studies the effect of cooking high-tannin sorghum has been evaluated in rat-bio assays (Price et al. 1980, Eggum et al. 1983). Although the amount of assayable tannin was greatly reduced when high-tannin sorghum grain was boiled in water or soaked in water, the weight gain was even less and the protein digestibility significantly lower compared to rats fed untreated high-tannin grain. This effect of cooking was shown in low-tannin sorghum as well but to a minor extent. One explanation for this effect of cooking has been proposed by Guiragossian et al. (1978) who first demonstrated the high proportion of cross-linked kafirins in sorghum endosperm from both normal and high lysine grains. The possibility exists that the cross-linked kafirins in sorghum are involved in the formation of complexes with starch during cooking which then reduces availability to digestive enzymes.

Some few studies have been reported on the protein quality and digestibility of sorghum proteins in humans. Studies on young men and women in Nigeria fed dominantly sorghum diets showed low nitrogen retention compared to a rice diet (Nicol and Phillips 1978) and a lower digestibility of whole sorghum diets compared to decorticated sorghum diets (Cornu and Delpeuch 1981). Recent work by MacLean et al. (1981 and 1983) on Peruvian preschool children showed that whole sorghum flour gruel has a low nitrogen retention compared to a casein control diet and a mean absorption of only 47%. Decortication and extrusion treatment increased the apparent digestibility to 81% not different from the control wheat diet. These findings are controversial since the children had just recovered from PEM and the digestive capacity certainly needs a longer time to be fully recovered. In a study by Svanberg et al. (1984b) on healthy Ethiopian preschool boys the digestibility for a sorghum based diet (85% extraction rate) was reported to be 70%, somewhat lower than 78% measured on a wheat flour reference diet.

3.2.2 Sorghum Protein Digestibility in vitro

Sorghum digestibility tests on young children were rare in the reviewed literature, because these trials are costly and require sophisticated facilities and personnel. Therefore several rapid and simple in vitro methods have recently been developed to predict the values for human subjects.

Hsu et al. (1977) described an in vitro enzymatic method using an enzyme system consisting of trypsin, chymotrypsin and peptidase and found a correlation coefficient of 0.90 between in vitro values and apparent protein digestibility determined on rats for 23 different plant protein sources. Rich et al. (1980) indicated that a 4-enzyme in vitro assay was able to predict both human and rat in vivo apparent digestibilities with correlation coefficients of 0.86 and 0.76, respectively. On the other hand Bodwell et al. (1980) concluded that for mixed protein sources, plant and animal, the in vitro enzymatic procedures gave only an approximate estimate of digestibility in humans. The 3- and 4-enzyme systems were further tested by Pedersen and Eggum (1981) and were found adequate for measuring protein digestibility in samples of plant origin as well as mixtures of plant and animal proteins showing a correlation of 0.90 with in vivo data on rats. A recent study on the in vitro digestibility of sorghum proteins using a pepsin digestion method (Axtell et al., 1981) reported similar digestibility values to those found in studies on pre-school children using the same sorghum cultivars (MacLean et al., 1981). The same in vitro method has been shown to be sensitive to the presence of tannins i.e. high-tannin sorghum varieties (Chibber et al., 1980). In related studies, treatment of high tannin Tanzania sorghum with magadi soda ($Na_2CO_3NaHCO_3 \cdot H_2O$), at a concentration of 4 g/liter for 3 days, reduced assayable tannin and increased in vitro protein digestibility by pepsin (Muindi et al. 1981).

3.2.3 Attempted Solutions

From the aforementioned it is evident that the main problem in sorghum protein utilization is poor quality due to the amino acid composition and low digestibility due to a variety of reasons such as the presence of polyphenols which is dealt with separately in the next section (3.5) and high fibre content.

The amino acid content of sorghum has been tackled by plant breeding incorporating the discovery of the high lysine gene in Ethiopia (Singh and Axtell 1973) and the chemically induced high lysine mutant by Mohan (1975). Both have higher protein content, about 15%, and a higher lysine content of 2.9% expressed as percentage of protein, compare to 1.2% for normal sorghum (Ejeta 1976).

However, early in the study the genes introduced poor physical characteristics namely floury rather than flinty properties which make final food products such as porridge, acquire poor physical properties compared to normal sorghum, but with superior flavour and palatability (Axtell et al. 1982). The plants are also susceptible to diseases, pests and tend to yield low so this solution may not be easy to implement at grass root level.

Supplementation of sorghum gruels for weaning foods by high protein sources such as legumes (Pushpama and Devi 1979, Brandtzaeg et al. 1981, Okeiyi and Futrell 1983) has been attempted mostly by formulating industrial level units. This approach needs sophisticated technology and produces expensive products (Orr 1972) which poor rural communities cannot afford. The original concept that protein deficiency was the major malnutrition problem no longer holds (FAO/WHO 1973) since energy shortage or rather shortage of food as such, seems to be the major causal factor in child malnutrition.

The formulation of multimixes at home containing a balanced source of nutrients using local foods has been advocated by Jelliffe (1968) and Cameron and Hofvander (1976). However this approach to meet the nutrient needs of an individual and poor protein quality requires increasing the intake according to FAO/WHO 1973. This is not easy, however, especially for children when a high bulk diet such as sorghum porridge is consumed.

Milling of sorghum improves digestibility by the removal of the seed coat which contains some antinutritional factors such as fibre and polyphenols (Chibber et al. 1978, Maclean et al. 1983, Pedersen and Eggum 1983). However, the removal of these factors is incomplete, while more thorough milling removes the aleurone layer and the germ which are rich in nutrients especially protein, lipids and minerals (Eggum et al. 1982).

Germination of sorghum apart from production of starch digesting enzymes, also alters the amino acid content in the grain. The most limiting amino acid lysine increases and hence biological value (Dalby and Tsai 1976, Wu and Wall 1980, Taylor 1983 and Sathe et al. 1983). It also increases the vitamin content (Fordham et al. 1975) especially vitamins of the B group and vitamin C all. This simple natural technique therefore offers a cheap practical solution to the problem.

3.3 Iron

Iron occurs widely in nature and in foodstuffs. Animal products and dark green vegetables are among the richest sources, while among cereals, sorghum and millets are important sources (Latham 1965). Iron is an essential trace element in human nutrition and a daily intake of 10 mg/day for adult males and 18 mg/day for adult females (Mertz 1981, Mertz 1984) has been recommended, though there is a wide variation in body demand determined largely by age, sex and nutritional status.

Iron is present in all cells in the body and is essential because of its key role in the haeme molecule which permits oxygen and electron transport. Among others, it is an important constituent of haemoglobin.

Iron deficiency causes nutritional anaemia with subsequent inadequate nutrient assimilation and loss of vitality in humans and animals (Mertz 1981). It is a public health problem of prime importance and as seen earlier, this condition affects a large population of sorghum staple areas since iron is generally poorly absorbed in cereal products (Amine and Hagsted 1971, Hallberg et al. 1981).

3.3.1 Iron Absorption and Availability

Human studies using the extrinsic radio iron tag method have yielded some useful information on iron availability and absorption in cereal based diets (Bjorn-Rasmussen 1983). Although cereal diets seem to contain sufficient iron, only a small fraction (1-5%) of the iron in rice, maize and wheat respectively have been found to be absorbed (Cook et al. 1972). There is good evidence that the poor bioavailability of iron is due to substances that inhibit iron absorption (Gillooly et al. 1983). Three groups of substances found in cereals, namely phytates, polyphenols and fibre (as indicated later in this review), have been proposed as inhibitors of iron absorption. The iron-absorption was accordingly significantly lower in a high-tannin sorghum variety, 1.9%, compared to 4.3% in a white variety that lacked polyphenols (Gillooly et al. 1984). The phytate-rich fractions of the sorghum (i.e. the bran) as well as some constitutents of the fibre fraction, hemicellulose and lignin, also significantly reduced iron absorption. However, the use of human subjects and the administration of radionucleides to humans is not always possible.

Both animal absorption studies and in vitro methods have been proposed to measure the availability of dietary iron. Only a few studies though, have compared these methods with human absorption studies. The value of animal studies may be limited due to differences in human and animal iron metabolism (Finch et al. 1978). Of the methods proposed for evaluating the biological availability of iron with rats the haemoglobin repletion assay in which anaemic animals are used, has been recommended when the purpose is to assess the ultimate possible contribution of a product to iron nutrition (Amine and Hegsted 1974, Miller 1982b). In this procedure, reference standard and test diets containing three or more levels of iron from the respective sources are fed and relative biological value (RBV) of iron in the test diet is compared to that of the reference compound by regression techniques.

In vitro methods offer an appealing alternative to human and animal studies, since bioassays are very expensive and laborious. A variety of in vitro methods have been proposed (Narasinga Rao and Prabhavathi 1978, Lock and Bender 1980, Miller et al. 1981) most of which attempt to simulate gastrointestinal conditions. The food is extracted with pepsin-HCl at low pH and subsequently the pH is adjusted to pH 7.5 and amount of ionizable iron determined. A high correlation has been shown between these in vitro methods and physiologically available iron in humans (Narasinga Rao and Prabhavathi 1978, Schricker et al. 1981).

Furthermore, in vitro methods have shown promise in predicting the bioavailability of contamination iron in foods which is not likely to be appropriately estimated by the extrinsic radioiron tag method in human studies (Prabhavathi and Narasinga Rao 1981, Hallberg and Rasmussen 1981). Usually the iron content of cereals are several times higher than the native content due to contamination from dust during harvesting, transport and storage. However this contamination iron seems not to be available for absorption in most cases.

3.3.2 Relevant Causal Factors for Iron Deficiencies

From the aforementioned, it appears that iron deficiency in animals and humans has several causal factors. The initial inherent dietary iron content and the source, determine whether the iron is haeme or nonhaeme and hence availability. Since iron absorption is inhibited by phytates, polyphenols and fibre, all of which occur substantially in sorghum, it is highly suggestive that iron availability from sorghum is problematic.

Even if analysis of the total iron content in the food indicated a sufficient level, however, only a small proportion might be available for absorption. This could include a large amount of contamination iron which might not, be available for absorption (Hallberg et al. 1983). Other causes of iron deficiency especially in rural cereal staple areas, are the prevalance of diseases such as malaria which deplete body iron, heavy infestations of parasites like hook-worms and round worms which literally suck blood from their victims (Maletnlema 1977 and Kimati 1977).

3.3.3 Solutions Tried Out

Relating the aforementioned to the anaemia problem in sorghum eating areas, potential solutions include supplementation or fortification of foods such as bread (Fearweather-Tait 1982) or other carriers like sugar or salt but the iron may be poorly absorbed (Morck et al. 1981). Since the demonstration that dietary non-heme-iron is absorbed from a common pool which means that iron salts added to a particular diet are absorbed to the same extent as the non-heme-iron present in that diet, the value of fortification has been questioned (Elwood 1968). Presumably the dietary factors that restrict the absorption of the native iron in the cereal have a similar effect on any added iron.

The use of processing methods which reduce or remove the components that inhibit iron absorption and the use of promoting agents like ascorbic acid have been suggested as a more rational approach. Dehulling of the grain usually means a substantial reduction of the inhibitory components like phytate, polyphenols and fibre. Although dehulling also can result in a substantial loss of other nutrients, as well as iron itself.

The use of vitamin C-rich fruits and vegetables in a cereal based diet will inevitably enhance the iron absorption in such diets (Derman et al. 1977). Vegetables and fruits are only available seasonally. Wider use of iron-rich sources (meat, fish and dark green vegetables) is feasible but meat is expensive and again vegetables are abundant only during the rainy seasons while severe scarcity occurs during the dry season.

Again germination may offer a solution in sorghum consuming communities as it has been observed that germinated legumes and other cereals have improved nutrient availability and reduced levels of factors such as phytates and tannins which inhibit iron absorption.

3.4 Zinc

Zinc occurs widely in nature among plants and animals and has for decades been recognized as an essential trace element in animal and human nutrition (Mertz 1981).

The importance of zinc in human nutrition was high-lighted by the work of Prasad et al. (1963) in Iran and Egypt while studying zinc deficiency in predominant cereal diets (whole unleavened wheat, maize and millets) in young children. This stimulated much research in the last three decades in animals and humans and has been widely reviewed as reported by Becker and Hoestra (1971), Mertz (1981), Sandstead (1981), Solomons (1982), Sorenson and Butrum (1983). Recently Moser and Allen (1984) while studying zinc intake of lactating and non-lactating women and their infants reached a similar conclusion. The element is of public health importance as indicated in the literature reviewed. Among its many body functions, it takes part in enzyme metabolism involving energy.

The required daily allowance (RDA) is 15 mg for adults, but the RDA during pregnancy and lactation is 20 and 25 mg respectively (WHO 1973). Deficiency of zinc occurs mostly in cereal staple population groups, sorghum included, and results in low appetite, growth depression, skin lesions, sexual immaturity, poor immunity and loss of taste. Excessive zinc intake can also be toxic. The above therefore underscores the importance of zinc in human nutrition.

3.4.1 Zinc Absorption and Availability

Zinc absorption in animals and humans is highly variable (Becker and Hoestra 1971) and depends on biological factors such as species, age, gastrointestinal infection and dietary zinc content (Flanagan et al. 1983, Shah and Bolonje 1984). It therefore appears that zinc availability is influenced by many factors as indicated in the literature cited above and it also depends on the form in which zinc appears in the gut. Also, zinc forms phytate complexes which inhibit its availability (Odell et al. 1972).

The protein source in the diet is an important factor as well as the quantity of animal sources. Large amounts of animal proteins in the diet increase availability as they have no inhibitors, while seed types have (Solomons 1982, Welch et al. 1982, Cossack et al. 1983 and Fuad 1983). The presence of other cations and their proportions is another factor as reported in human intestinal tin and zinc interaction (Solomons 1983).

The fibre component from cereals form complexes with many cations and the most studied factor in the bran affecting zinc availability is phytic acid as reviewed by Maga (1982) and other recent studies using animals mainly rats (Davies and Olpin 1979, Morris and Ellis 1981). Phytate has been reported in sorghum and sorghum products (Doherty et al. 1982) and could influence zinc availability in the varieties under study.

Some studies on adults also concluded that the cellulose (Ismael-Beigi 1977) fraction of the bran has negative effects on zinc balance. However others have reported no effect of fibre on zinc availability (Sandstead 1978).

3.4.2 Pertinent Causal Factors for Zinc Deficiencies

From the above mentioned it is apparent that zinc deficiency may be caused by dietary factors which are of particular interest in the present study since unprocessed sorghum staples, may contain high levels of fibre, phytic acid and polyphenols. The zinc requirements of populations dependent on sorghum may also be enhanced due to increased losses through parasite infestations and diseases (Sandstead et al. 1967).

3.4.3 Attempted Solutions

Practical solutions attempted in combating zinc malnutrition include diet formulation incorporating high zinc sources such as meat while composite meals including cereals and legumes have been tried in the laboratory (Sandström et al. 1980). This approach may not be tenable in sorghum staple areas where the required food materials are not readily available all the time or are expensive.

Milling of cereals removes some inhibitors but also lead to the loss of other major nutrients (Faridi et al. 1983). On the other hand sorghum is not easy to decorticate on a large scale using current methods due to the bran being closely bound to the endosperm, as already stated earlier in the present study.

Fermentation as practised in bread making reduces phytates and may make zinc more available (Amoa and Muller 1976, Faridi 1983). This is actually practised in the Sudan and India using sorghum (Rooney and Murty 1982). However, this practice requires introduction and promotion in rural Tanzania. Use of chemicals for supplementation and fortification (Solomons *et al*. 1979, Roxas *et al*. 1981) are expensive and may not be feasible in rural areas as reported in Guatemalan diets.

On the other hand, germination is widely practiced for beer making as reported earlier and beer has better nutrient availability but this is mainly consumed by adults. Using the germinated grains for gruel making especially for weaning foods might provide improved dietary zinc availability since better zinc availability occurs in other germinated seeds such as wheat (Ferrel 1978).

3.5 Tannins

Tannins occur widely in plants and provide a natural protective mechanism or acceptable level of astringency. The chemistry of tannins leads to its definition as a polyphenolic compound capable of precipitating proteins from aqueous solutions (Swain 1965, Ologhobo 1983) with wide ranging molecular weights, mostly within 500 to 3000. The major plant tannins are either hydrolyzable or condensed tannins, the latter being mainly procyanidins and have been reported in sorghum (Gupta and Haslam 1980, Oberthur *et al*. 1983).

3.5.1 Tannins in Sorghum

Comprehensive reviews on sorghum tannins have been given by Price and Butler (1980b) and Butler (1982).

The structure proposed for sorghum tannins by Gupta and Haslam (1978) indicates, that it is an oligomer of five to seven flavan-3-ol

units. In addition to these oligomers, many monomeric and dimeric flavanols have been reported in sorghum. Several chemical assays have been developed to measure the tannin present in sorghum especially methods which detect different characteristics of the molecular structure.
The different chemical assays for tannins usually correlate well with measurement of anti-nutritional effects in feeding trials with rats and chicks. Of the various procedures of tannin analysis which have been critically evaluated by Maxson and Rooney (1972), only one, which utilizes the efficiency of precipitating proteins, is relatively specific for vegetable tannins. This method, gelatin precipitation, however, was found to be unreliable.

On the other methods investigated only three were judged to have potential use for the analysis of polyphenols and tannins in sorghum grain and perhaps the most widely used assay for sorghum tannins is the vanillin reaction (Burns 1971). Its principal advantage, is that the only plant phenols with which it gives a positive test, are the condensed tannins and some flavanoids.

The method has been critically evaluated and modified by Price et al. (1978a) and uses catechin as a reference standard. Acidic methanol is required to extract the tannins and only from dried samples of sorghum flour. A water content of 16% or greater or boiling immature grain in water and drying reduces tannin content measured by this method (Price et al. 1979a). If water is used in the preparation it will permit the formation of insoluble tannin - protein complexes from which tannin to some extent cannot be extracted (Price et al. 1980a).

Tannins in sorghum vary widely in type and content and depend on sorghum genetics and ecology (Asquith et al. 1983, Taylor and Schussler 1984). The tannin content is often associated with the presence of testa in the seed (Blackley et al. 1979) and imparts colour to the grain. Consequently sorghum is classified as white or tan if low in tannin (L.T.) or red or brown if high in tannin (H.T.) content. Another classification is "none bird resistant" types which are low in tannin and "bird resistant" types which are high in tannin (Bullard et al. 1980, Subramanian et al. 1983a). Subsequently most of the literature on sorghum tannins in relation to nutrition compares the two classes.

3.5.2 Nutritional Effects of Sorghum Tannins

The nutritional effects of tannins in sorghum have been widely studied using mainly animals with very limited work on humans. Price and Butler (1980b) have reviewed and summarized the topic comprehensively. Poultry, mostly chickens have been used in many studies because sorghum is widely used in feeds. Natural tannins from the seed and reagent grade tannic acid have been used with wide ranging findings either expressed as growth responses or Protein Efficiency Ratio (PER) (Vohra et al. 1966 and Armstrong et al. 1973).

In summary low levels of tannins at about 0.1% in chicken diets show no growth depression but levels between 0.5 and 2% depress growth (Chang and Fuller 1964) while tannic acid at 5% causes heavy mortality (Vohra et al. 1966). Growth depression with poor PER occured in chicks fed high-tannin sorghum compared to low-tannin sorghum (Armstrong 1973).

Work in rats gave findings comparable to those in chickens. Rats fed diets containing 4% tannic acid had severe growth depression due to low food intake (Glick and Josylin 1970) and death occured at 8% tannic acid content within a week. Rats fed some high-tannin genotypes of sorghum gave lower weight gain and feed efficiency than those fed low-tannin types (Jambunathan and Mertz 1973, Schaffert et al. 1974). However, addition of protein (15% soy bean meal) reduced the difference to a level of no significance. Ruminants however show no serious negative effects from high-tannin sorghums possibly due to the nature of their digestive tracks (Mangan 1972).

Human studies using sorghums food products are very few and have indicated that whole flour sorghum has low protein digestibility (McClean et al. 1981).

3.5.3 Cause of the Antinutritional Effects of Tannins

Suggested explanations for the antinutritional effects of tannin in the diet have been principally along the following lines, (a) Tannin depresses food/feed intake, (b) Tannin complexes with dietary compounds, (c) Tannin complexes with digestive enzymes, and (d) Toxicity.

(a) Food intake depression with subsequent slow growth has been reported in rats fed rations containing tannic acid (Glick and Joslyn 1970) and chicks (Vohra 1966). On the other hand palatability of feeds with naturally occuring tannins, was not a serious problem in sorghum fed rats (Featherston and Rogler 1975 and Schaffert et al. 1974) where the high-tannin diet had higher consumption but still produced slow growth rates.

(b) Tannin Dietary Protein Complexes occur whereby tannins bind and precipitate proteins as reported in recent investigations (Hagerman and Butler 1980 and 1981, Reichert 1980). Earlier studies showed decreased protein digestibility in rats fed high-tannin sorghum (Martin-Tanguyet al. 1976), thus suggesting a nonspecific binding of food/endogenous proteins with tannins.

Increased excretion of endogenous protein is indicative in studies on chicks given high-tannin sorghum (Elkin et al. 1978) and in rats given tannic acid and casein (Glick and Joslyn 1970). The latter also found a 3- to 4-fold increase in levels of intestinal proteolytic activity.

(c) Interference with the action of digestive enzymes by dietary tannin might be expected in view of the general protein binding capacity of tannin. High tannin content of some sorghum grain-hybrids inhibits amylase activity (Maxson et al. 1973, Daiber 1975). A considerable increase in trypsin and amylase activity in the fecal contents of rats fed carob condensed tannins was found and a strong inhibitor effect on the digestive enzymes trypsin, alpha-amylase and lipase (Tamir and Alumot 1970 and 1969).

(d) Toxicity. A reasonable assumption was made by Singleton and Kratzer (1969) that the direct absorption of a hydrogen-bonding, nondialyzable, protein-precipitating macromolecule like tannin is unlikely in the normally functioning animal. The evidence for the harmful effect of tannin on body tissues comes therefore from experiments in which it was not administered orally. Injected into animals it causes mortality and is highly carcinogenous (Bichel et al. 1968).

3.5.4 Attempted and Potential Solutions to Tannin Antinutritional Effects.

Endeavours to overcome undesireable effects of tannins have so far been limited and vary according to the types of food stuff, so only those related to sorghum are reviewed in the present study.

Physical removal of tannin has been achieved by removal of the seed coat using various techniques such as recent mechanical decortication (Shepherd et al. 1971-72, DeFrancisco et al. 1982, Cagampang et al. 1984). However this method is ineffective where tannins are also present in the endosperm, and leads to substantial nutrient losses. Meanwhile power sources are not easily available in rural areas. Treatment with hot alkali and washing removes the seed coat too, but the product may be more suitable as feed for animals rather than human food (Featherston and Rogler 1975). Anaerobic storage of tannin sorghum seed using water, mild hydrochloric acid sodium chloride, under carbon dioxide reduced tannins (Reichert et al. 1980). A variety of mild alkaline treatment of high-tannin sorghum grains lowered polyphenol content without loss of seed components. Moistening the grain with dilute ammonium hydroxide or 0.5 M potassium bicarbonate had similar effects and improved weight gain in rats (Price et al. 1978a and 1979b). However, these treatments require chemicals which are not easily available in relevant areas and some are expensive anyway.

Heat treatment of high-tannin sorghum by dry heating or micronization did not decrease assayable tannin. However boiling the grain in water then drying reduced the the measurable amount of tannin considerably (Glennie et al. 1982).

Germination of sorghum offers promise especially in combination with mild alkaline treatment where the alkaline reduces the tannin content (Doggett 1977). Meanwhile the germination biochemical process itself reportedly reduces extractable polyphenols in some sorghum varieties (Daiber 1975) though similar observations are very limited such as Fenugreek seed (El-Shimi et al. 1983 and Glennie 1983) while studying sorghum during malting. The limited work done in the effects of germination on nutritional value, necessitated more investigation.

CHAPTER IV

4. MATERIALS AND METHODS

4.1 Sorghum Grain

The local sorghum varieties used in this study were collected from Dodoma region which is a major sorghum staple region in the country. The improved varieties (higher in yield, short stems and early maturing) were obtained from the Tanzania Agricultural Research Organization Institute at Ilonga in Kilosa. A trip was made to Ilonga and all the four districts in Dodoma (four villages were visited in each district) at the middle of the sorghum growing season to observe the condition of the crop and identify potential suppliers of good experimental material. The selected areas were visited at harvest time and samples were collected.

One of the local and improved varieties were of the white (low-tannin) type of sorghum and the others were brown (high-tannin) types. The respective variety names are:

	White	Brown
Local	Lugugu	Udo Msonga
Improved	ET.35-1	5DX 135/13/3/1

A composite sample of Lugugu was obtained from Hombolo village in Dodoma Rural district, while Udo Msonga was collected from Mungoroma village in Kondoa district.

For the sake of abbreviation, the following shortened names are used in the text: Lugugu, ET 35, Udo and 5 DX to designate the varieties.

Grain characteristics. The characteristics of the grain are summarised in Table 5, showing colour and mean weight of 100 seeds by the procedure of Kapasi-Kakama (1977).

Table 5. Grain Characteristics of Sorghum (100 seed)

Variety	Colour	Mean weight of (g)	% of Floury Endosperm	Classification
ET 35	Creamy white	3.17	18	Flinty
5 DX	Brown	2.81	88	Floury
Lugugu	Creamy white	1.71	9	Flinty
Udo	Brown	1.71	44	Floury

The endosperm texture rating of the varieties studied showed that ET 35 and Lugugu were classified as flinty, while 5 DX and Udo were floury. This was according to the method described by Kapasi-Kakama (1977) whereby 100 grains were bisected and visual observations made. The findings are summarised in Table 5.

4.2 Germination of Sorghum Grain

4.2.1 Traditional Germination Procedure

The grain was germinated using the traditional method. The grain was washed in an iron pail in excess water till the supernatant liquid was clear and was left soaking overnight with the water filled up to 15 cm above the level of the grain. This ensured enough water for the grain to absorb. The next day (16 hours later), the grain was washed three times in an excess amount of water. Green grass was laid out flat on a hardened earthen floor at a dark corner of the house. The wet grain was put in a clean gunny bag, the open end tied with a string and the contents spread out to form a layer, about five centimeters thick. The bag was sprinkled with water and covered with more grass to form a completely dark environment. After 24 hours the grain was washed thoroughly to remove any mould growth, and returned into the sack and covered with grass. (This latter washing was a modification of the traditional method to limit micro-organism growth and the same was done after 48 hours germination). At the end of 48 hours, the grain was removed, sun dried for two days and kept in a cool dry place till it was required.

The following climatic conditions were observed when the samples were germinating and drying at Ilonga near the meteorological station (Table 6).

Table 6. Conditions During Germination and Drying of the Sorghum Varieties at Ilonga Village in Kilosa

	Germination	Drying
Average temperature		
Maximum ^{o}C	26.9	28.8
Minimum ^{o}C	13.6	13.2
Mean ^{o}C	20.2	20.3
Relative humidity %	44.5	38.3
Sun-shine hours/day	8.8	9.6

4.2.2 Laboratory Germination Procedure

The traditional germination procedures at village level in Tanzania were adopted to laboratory conditions as follows: before washing, the seeds were soaked in 70% ethanol for two minutes to prevent the growth of microorganisms. The seeds were then soaked in the same amount of water and kept in the dark for 12-20 hours. After washing in distilled water, the seeds were spread in a one cm thick layer between wet cotton cloth and left to germinate in the dark for 48 hours at room temperature (20^{o}C). The sprouted seeds were dried on a plate in an air stream oven at 50^{o}C and the dried seeds with their vegetative portion were milled in a laboratory plate mill.

4.2.3 Germination Potential

The four sorghum varieties under study were germinated for 48 hours under ambient local conditions as summarised in Table 7 and the potential is given in Table 7.

Table 7. Percentage of Germinated Seeds within 48 hours.[a]

Variety	After 3 months storage at 20-25°C
ET 35	91.0
5 DX	91.0
Lugugu	99.0
Udo	91.2

[a]1000 seeds were examined for each variety.

All the varieties had high germination percentages, ranging from 91% for three of the varieties to 99% for Lugugu. This was acceptable bearing in mind that these particular samples had been stored at ambient temperature for three months.

4.2.4 Malt Development

The grain used in the study had the following malt development characteristics. The growth of the root and shoot of the seeds was recorded after 48 hours and the observations are presented in Table 8.

Table 8. Malt development as indicated by root and and shoot growth (mm)[a].

	ET 35-1		5 DX		Lugugu		Udo	
	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot
Mean	10.82	2.64	10.60	2.86	11.70	2.40	10.54	2.66
S.D.	+2.76	+1.17	+2.89	+1.10	+2.45	+0.99	+2.26	+1.36

a)Average of 1000 seeds in batches of 100 each after 48 hours germination.

In all the varieties, root growth was more rapid than shoot growth, averaging 10.9 mm with a standard deviation (S.D.) of +2.59. Lugugu was most prolific averaging 11.70 mm in root growth. The average shoot growth was only 2.64+1.16 mm.

The moisture content of the seed before and after germination is presented in Table 9.

Table 9. Moisture Content of Sorghum Grain (%)[a]

Variety	Initial (as collected)	After traditional germination	After laboratory germination
ET 35	14.4	37.1	37.5
5 DX	15.0	39.0	40.0
Lugugu	12.7	33.0	33.4
Udo	12.8	40.5	41.0

[a]Oven dried at 105°C to constant weight.

The initial moisture content of the grain as collected (12.7-15.0%) was too close a level where mould growth could develope and so the grain was dried to a safe 11% moisture level and stored in a cold room (+5°C) using air tight containers, till it was required. The moisture content of the seeds after traditional and laboratory germination for 48 hours, was almost the same for the same variety.

There were differences between varieties ranging from 33% to 40.5% for moisture content, using the traditional method, implying that Udo and 5 DX retained more water than Lugugu and ET 35. This was expected since Udo and 5 DX were floury while the other varieties were flinty in texture.

4.2.5 Soluble Amylase Development

The grains developed soluble amylase as observed for four days. This is summarised in Table 10.

Table 10. Soluble Amylase Developement During Germination: Phadebas Amylase Units[a)]/g of Seed.

Days	0	1	2	3	4
Sorghum	(Amylase Units x 1000)				
ET 35	1.7	38	63	220	320
5 DX	0.1	4.3	46	120	580
Lugugu	0.3	66	280	490	660
Udo	0.8	5.7	23	38	64

[a)]Phadebas Amylase Method (Mundy 1982 Carlsberg Research Centre,Copenhagen. Moisture content as shown in Table 9.

Initially all varieties had inherent soluble amylase activity which increased rapidly during the four days of germination. Lugugu had the fastest development, reaching 660 thousand Phadebas units per gram of seed, followed by 5 DX with 580 thousand units. While ET 35 reached 320 thousand units Udo had the lowest of 64 thousands, only about a 10th compared to Lugugu. The germinated flour from the samples activity, was used for the bulk reduction studies and field application at village and household level as reported in the next chapter.

4.3 Milling

4.3.1 Traditional Dehulling of Samples

Traditional mortar and pestle dehulling was done as described in detail by Eggum *et al*. (1982). The grain was sprinkled with water, lightly pounded in the mortar and the bran winnowed off. The procedure was repeated till an acceptable flour was produced (about 80% extraction). Both ungerminated and germinated samples of Lugugu, ET 35 and Udo were traditionally decorticated. 5 DX and germinated Udo were too floury and easily disintegrated during the pounding. The dehulled grain was finally milled in a local diesel powered hammer mill and kept at room temperature (25-28^{0}C) for two weeks when it was air freighted to Sweden and held at +5^{0}C till it was required.

The particle size distribution of traditionally decorticated and hammer milled flour is summarised in Table 11. Particle size of the flour is important as it affects texture and bulk. The analysis was done by seiving and shaking in an Alpine unit (Alpine-Duisberg-W.Germany).

Table 11. Particle Size Distribution of Traditionally Decorticated and Hammer Milled Sorghum (Percentage).

	Screen Size in Microns					
	1000 (over)	1000-500	500-250	250-125	125-63	63 (under)
ET 35						
Ungerminated	1.0	20.0	31.5	20.0	12.5	15.0
Germinated	1.5	20.0	30.5	18.5	11.5	18.5
Lugugu						
Ungerminated	1.0	21.0	34.0	20.0	12.0	12.0
Germinated	1.0	19.5	31.0	18.5	16.0	14.0
Udo						
Ungerminated	0.5	16.5	28.0	19.5	14.5	21.0

The flinty varieties (Lugugu and ET 35) had most of the flour between 125 and 1000 microns: while floury Udo had most flour within 63 and 500 microns indicating vigorous grain structure breakdown during milling.

4.3.2 Abrasive Decortication

Abrasive decortication was done in a dehuller developed by the International Development Research Centre (IDRC, Ottawa, Canada) the PRL/RIIC model and was located at Chanzuru in Kilosa district. The mill has been described in detail by Eastman (1980). Debranning was achieved by carborundum stones rotating fast within the grain in the milling chamber. The bran was cycloned off and the clean grain was removed through an adjusted over flow outlet. The decorticated grain was then hammer milled and kept till needed.

4.3.3 Laboratory Milling

The samples for analysis were milled in a plate mill (Falling Number AB, Stockholm, Sweden) and seived where necessary to desired extraction rates. Whole clean grain was used. Most of the samples for rat studies were milled in a bigger capacity laboratory plate mill (Diamant Grand Prix, Rio, Brazil).

The characteristics of particle size distribution of whole grain germinated and ungerminated flour used in our studies are summarised in Table 13 with most flour being between 125-500 microns.

Table 12. Particle size distribution of laboratory plate milled whole sorghum flour (%).

	Screen Size in Microns				
	500 (above)	500-250	250-125	125-63	63 (under)
ET 35					
Ungerminated	0.5	27.0	39.0	17.5	16.0
Germinated	7.5	40.5	22.0	18.0	12.0
5 DX					
Ungerminated	1.0	26.5	36.0	17.5	19.0
Germinated	11.5	34.0	17.5	11.0	26.0
Lugugu					
Ungerminated	1.5	43.5	33.0	10.5	11.5
Germinated	4.5	41.0	23.5	12.5	18.5
Udo					
Ungerminated	2.0	34.5	33.0	13.5	17.0
Germinated	3.5	34.5	26.0	15.0	21.5

4.4 Preparation of Cooked Samples

Samples for rat studies and enzyme digestibility were cooked in ordinary aluminium pots using 95%, 90%, 80% and 70% distilled water over an electric hot plate for 20 minutes. However, for the Iron and Zinc studies, in order to minimize contamination, the gruels were cooked in deionized water in stainless steel utensils.

Where needed, the gruels were freeze dried in a Modulyo drier supplied by Edwards High Vacuum, Crawley, U.K., then milled in the laboratory (Diamant Grand Prix Plate Mill) and kept in plastic containers at +5^{o}C till required.

4.5 Analytical Methods

4.5.1 Proximate Analysis (Association of Official Analytical Chemists-Horwitz 1975)

Moisture was determined by oven-drying of 4 g of sample at 105°C to constant weight. Ash was determined after dry-ashing of the sample at 450°C over night, addition of a few drops of concentrated nitric acid and continued ashing under cover until a white or yellow residue remained. A Gallenkamp adiabatic bomb calorimeter was used for energy measurements. Nitrogen analysis was performed by micro-Kjeldahl technique in a Technicon Autoanalyzer. The nitrogen values were converted to crude protein values by a factor of 6.25. Fat was determined with ether extraction.

4.5.2 Amino Acid Assay

Amino acid assay was done on a JEOL amino acid analyser (JEOL-5AH, Japan Electron Optics Laboratory Co. Ltd., Tokyo, Japan). Samples were hydrolysed using 4N methanesulphonic acid as described by Simpson et al. (1976). Cysteine was determined as cysteic acid after performic acid oxidation (Moore 1963) and tryptophan after hydrolysis in sodium hydroxide (Hugli and Moore 1972).

4.5.3 Fatty Acids

Fatty acid analysis was done by the method of Folch et al. (1957). The homogenized samples were extracted in 2:1 chloroform-methanol v/v. Following Folch's procedure, the fatty acid content was finally determined by High Performance Gas Liquid Chromatography. The equipment used was a Varian Aerograph Series 2100 Model 2100-20) with Integrator-Hewlett Packard 3380A. (The equipment was supplied by Varian Instrument Group, Palo Alto, Ca., USA).

4.5.4 Dietary Fibre and Uronic Acids

The method used to determine the fibre content was based on Hellendoorn's enzymatic method (Asp *et al*. 1983, Hellendoorn *et al*. 1975) with the following modifications. The *in vitro* enzyme digestion was performed with pepsin at pH 1.5 for 1 hour and with pancreatin at pH 6.8 for 1 hour, thus simulating the conditions in the human gastrointestinal tract. Insoluble fibre components were recovered by filtration and soluble components by ethanol precipitation followed by filtration. The filtration was carried out with Tecator's Fibertec System (Tecator AB, Hogans, Sweden), using about 0.5 g of celite as a filter aid. The insoluble and soluble dietary fibre fractions thus recovered were dried overnight at 105°C before weighing. They were then analyzed for residual nitrogen by the Kjeldahl method (conversion factor to protein = 6.25).

Uronic acid was assayed by the method of Bylund and Donetzyhuber (1968) without modification. The samples were decarboxylized with hydriodic acid and the carbon dioxide formed was absorbed in a barium hydroxide solution whose conductivity change was measured and plotted. Uronic acid was then calculated from the curve.

4.5.5 Minerals

All minerals and phytin-phosphorus analyses were performed in acid washed glass-ware and only demineralized water was used in analyses. Duplicate samples for analyses of Fe, Zn and Mg were prepared by dry-ashing of about 0.6 g of milled sample at 450°C overnight. The ash was dissolved in 5 ml 5 M hydrochloric acid and allowed to stand under cover over night. The solutions were transferred with demineralized water to 25 ml flasks and made to volume.

Triplicate samples for Ca and P analyses were prepared by the wet-ashing of 0.1 g of flour in 1 ml sulphuric acid and 3 ml hydrogen peroxide for 15 min at 295°C. If the digest was not colourless the ashing was continued after adding another 2 ml hydrogen peroxide. The digests were diluted with demineralized water to 75 ml.

Iron, zinc, magnesium and calcium were determined against their blanks in an atomic absorption spectrophotometer (Perkin Elmer Model 360). Phosphorus was determined by a colorimetric method according to Fiske and Subbarow (1925). Estimation of phytin-phosphorus was done by the method described by the Nordic Committee on Food Analysis, Method 57 and 17 (Danish Technical Press, 1975 and 1966).

4.5.6 Vitamins

Vitamin determination was done by microbiological methods at the Vitamin Research Institute at Bergen in Norway. Thiamine was determined by using *Lactobacillus viridescens* 12706 ATCC from American Type Culture Collection, Rockwill, Md., USA. The AOAC method (1980) was followed whereby the sorghum flour (1 g) was extracted with 25 ml 0.1 N H_2SO_4 and treated with 25 M sodium acetate buffer to pH 4.5, 20 mg papain and 20 mg clarase were added and incubated at 37°C over night, steamed and cooled. The vitamin content was determined from a standard curve by turbidimetric measurement of the microbial growth at 660 nm.

Niacin was determined using *Lactobacillus arabinosis* ATCC (8014) from the American Type Culture Collection 12301. The AOAC method was used (1980) modified as follows. The sample (1-2 g) was extracted in INH_2SO_4, by autoclaving, adjusting to pH 6.5 with 4.5 acetic acid, inoculated and incubated at 37°C over night, autoclaved and cooled. The vitamin content was calculated from a standard curve by turbidimetric measurement of the microbial growth.

Vitamin C as dehydroascorbic acid, was determined by the Technicon Autoanalyser II industrial method No. 365-752-1/28/76 without modification (Technicon Industrial Systems, Tarrytown, N.Y., USA). Total ascorbic acid was determined using the method of Roy et al. (1976) whereby the acid was oxidized and measured by a microfluorometric method.

Pantothenic acid was determined using Lactobacillus arabinosis ATCC (8014) using the AOAC method (1980) modified as follows. The sample (1-2g) was extracted with 0.15 M sodium acetate buffer at a pH of 4.5, treated with papain and clarase, incubated at 37°C for 24 hours, autoclaved and cooled. Vitamin content was determined from a standard curve as in the case of thiamine.

Riboflavin was determined using the AOAC method (1980) and Lactobacillus Cassei. 1-2 g of sample were treated as described in the method, cultured, autoclaved and using a standard curve and the turbidimetric method, riboflavin was obtained. Extra care was practised to avoid destruction of the vitamin by direct sunlight.

4.5.7 Tannin content

Tannin content was determined as catechin equivalents by the vanillin assay (Burns 1971), modified by extracting 200 mg of a finally ground flour sample with 1% HCl in methanol for 20 minutes at 30°C (Price et al. 1978a). Determinations were done on the supernatant at the same temperature. The vanillin reagent was prepared daily by mixing equal volumes of 1% vanillin in methanol and 8% concentrated HCl in methanol was added (5 ml) at 1 minute intervals to 1 ml aliquots of the supernatant. The rest of the procedure as described by Price et al. (1978a) was carried out along with a standard catechin curve and the absorbance was read at

500 nm wavelength on a Beckman model B, spectrophotometer. The free tannin content was estimated to be 42% of the catechin equivalent obtained from the standard curve (Price et al. 1978a).

4.5.8 Aflatoxins

Aflatoxin was assayed by the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC 1980) edited by Horwitz. The samples were prepared as per method and so were the standards. All solutions were prepared in methanol and separated in minicolumns. Ultraviolet light was used for qualitative detection of aflatoxin.

4.6 Availability of Nutrients in Sorghum Grain

4.6.1 In Vitro Methods

(a) Protein Digestibility.

In vitro crude protein digestibility was determined using bovine pepsin as described by Axtell et al. (1981) and later by Mertz et al. (1984). The fine flour (200 mg) was suspended in 100 ml pepsin solution (0.5 mg/ml) in 0.1 M phosphate (pH 2.0) and incubated with gentle stirring at 37^{o}C for 2 hours. Blanks with pepsin were run simultaneously. The suspension was centrifuged and crude nitrogen determined in the supertanant which was expressed as percentage of total nitrogen in the sample. The value was the in vitro digestibility. In the modified method by Mertz et al. (1984), the nitrogen content of the undigestible residue was substracted from the total nitrogen content to give in vitro digestibility.

(b) Iron Availability.

In vitro iron availability was determined by the method described by Narasinga Rao and Prabhavathi (1978). Contamination iron was removed by washing with 0.1 N HCl and demineralized water (Suffian and Pittwell

1968) and dried before milling. The method measures non-haeme iron. Two g of the sorghum flour was mixed thoroughly with 25 ml of pepsin-hydrochloric acid solution (0.5% pepsin in 0.1 N HCl). The pH of the mixture was adjusted to 1.35 with distilled HCl and incubated at 37°C for 90 minutes in a metabolic shaker water bath. The contents were then centrifuged at 3000 rpm for 45 minutes and the supernatant filtered. An aliquot was adjusted to pH 7.5 with NaOH, incubated and treated exactly as the 1.35 aliquot. The supernatant was filtered and the filtrate was used for the determination of ionizable iron using alpha, alpha-dipyridyl to yield color as described by AOAC, 1980. This expressed as percentage of total iron, gave Fe availability.

4.6.2 In Vivo Methods

(a) Protein-Rat Bioassays.

(i) Protein Sources: Sorghum flour germinated or ungerminated and casein or white egg powder as control, were used as sources of protein. The sorghum samples used were previously cooked and freeze dried.

(ii) Biological Value (BV): True Digestibility (TD) and Net Protein Utilization (NPU) were determined by means of a balance method according to Eggum (1973) as described by Forsum (1975). Weanling male Sprague-Dawley rats were obtained from a commercial firm (Anticimex, Sollentuna, Sweden). Sixty rats (weighing 55-78 g) were used in the study. They were initially weighed and randomly divided into 9 groups such that the average weight between groups did not differ by more than 0.5 g. The rats were housed under conditions of controlled lighting (12 hours light, 12 hours darkness), a temperature of 28^oC and relative humidity of 40%. Faeces and urine were separately collected and total nitrogen content determined as described by Hambraeus et al. (1976).

(iii) The experimental diets were formulated to contain 10.5 g protein from sorghum and other components were added as shown in Table 13. The mineral and vitamin mixtures were formulated as described by Forsum et al. (1973).

The rats were provided with water ad libitum and daily weighed amounts of diet. The control casein diet was given in each trial.

Similarly 20 male rats, 21 days old, were used to study the effect of feeding supplemented raw sorghum diets. The diets were formulated from raw Lugugu and Udo flour and contained 50% sorghum nitrogen, 50% casein nitrogen and 1% methionine. The rest of the diet and procedures were as described by Eggum (1973).

Table 13 Composition of the Rat Bioassay Diets (g wet basis)

Diet		Flour	Corn Oil	Minerals	Vitamins	Cellulose Whatman CF11	Starch	Total
ET35	Ungerm	587.0	30.3	35.0	7.0	30.2	25.9	715.4
	Germ	571.0	30.4	35.0	7.0	30.5	42.6	716.5
5DX	Ungerm	574.0	19.6	35.0	7.0	24.6	60.3	720.5
	Germ	569.3	21.8	35.0	7.0	23.6	65.5	722.2
Lugugu	Ungerm	561.0	26.5	35.0	7.0	30.6	81.4	741.5
	Germ	17.1	28.4	35.0	7.0	31.3	105.5	724.3
Udo	Ungerm	618.0	21.5	35.0	7.0	23.5	7.9	712.9
	Germ	590.6	23.5	35.0	7.0	24.2	36.0	716.3

NOTE: The control Casein deit had the following composition:

Flour:	343 g
Corn Oil:	300 g
Minerals:	150 g
Vitamins:	30 g
Cellulose Whatman CF11:	158 g
Starch:	2349 g
Total Diet:	3330 g

(b) In Vivo Iron Availability in Rats.

Sorghum contamination iron was removed from the grain by washing with mild hydrochloric acid by the method of Suffian and Pittwell (1968). All germinated samples were handled in demineralized water, ash free paper and stainless cooking utensils.

The recommended AOAC method for evaluating biological availability of iron with rats is a hemoglobin repletion assay in which anaemic animals are used. The procedure described by Amine and Hegsted (1974) was used where a reference standard and test diets containing three levels of iron from respective sources were fed to rats and relative biological value (RBV) of iron in the test sources was compared to that of the reference compound by regression techniques (Hegsted et al. 1968 and Amine et al. 1972).

In this experiment the basal diet low in iron and test diets were formulated as indicated in Table 14 and Table 15. All the diets were formulated to contain 15% protein. Three levels of ferrous sulphate ($FeSO_4 \cdot 7H_2O$) were added to the basal test diets namely 10 ppm, 20 ppm and 30 ppm iron (Fe) to serve as standard references.

Table 14. Basal Low Iron Diet and Composition of Iron Free Mineral Mixture

Basal Diet	
Casein	20.0%
Starch	54.2%
Oil	15.0%
Cellulose	5.0%
Minerals (iron free)	5.0%
Choline Chloride	0.3%
Vitamins	0.5%[a]
Mineral Mixture (Iron free) (g)[b]	
NaCl	292.5
KH_2PO_4	816.6
$MgSO_4$	120.3
$CaCO_3$	800.3
KI	1.66
$MnSO_4 \cdot 2H_2O$	9.35
$ZnCl_2$	0.55
$CuSO_4 \cdot 5H_2O$	1.00
$CaCl_2 \cdot 6H_2O$	0.05

a) Hegsted et al. (1967)

b) Jones and Foster (1942)

Table 15. Iron Availability - Composition of Diets (g.wet basis)

Description of diet	Amount of sorghum (g)	Starch added (g)	Iron Cont. ppm
Basal+Lugugu-Ungerminated	386.3	20.3	20.8
	257.5	148.8	13.8
	128.8	177.5	6.9
Basal+Lugugu-Germinated	386.3	20.3	22.7
	257.5	148.8	15.2
	128.8	277.5	7.6
Basal+ET35-Ungerminated	386.3	20.3	10.8
	257.5	149.0	7.2
	100.0	306.5	2.8
Basal+ET35-Germinated	386.3	20.3	11.7
	257.5	149.0	7.8
	128.8	277.8	3.9
Basal+Udo-Ungerminated	386.3	20.3	23.4
	257.5	149.0	15.7
	128.8	277.8	7.8
Basal+Udo-Germinated	386.3	20.3	21.9
	257.5	149.0	14.6
	128.8	277.8	7.3
Basal+5DX-Ungerminated	386.3	20.3	13.3
	257.5	149.0	8.9
	100.0	306.5	3.4
Basal+5DX-Germinated	386.3	20.3	13.5
	257.5	149.0	9.0
	128.8	277.8	4.5

The basal diet contained: 159 g casein, 112.5 g of oil, 37.5 g of iron free mineral mixture, 3.75 g vitamins, 37.5 g cellulose and 2.25 g cholin chloride.

A total of 168 weanling male Sprague-Dawley rats aged 21 days were weighed and divided into 28 comparable groups of 6 rats each. The animals were housed in stainless steel cages in a room kept at 28°C and 40% relative humidity with 12 hours light/dark cycle. The animals were fed the diets and deionized water "ad libitum". The basal diet supplied less than 10 ppm of iron and was fed to all the rats, to deplete them of haemoglobin, for four weeks. The haemoglobin level was measured. If the haemoglobin was between 3 and 5 mg/100 ml the selected groups of animals were given the test diet. One group continued on the basal diet which was low in iron while three groups received test diets with 10 ppm, 20 ppm and 30 ppm of reagent grade hydrous ferrous sulphate which served as the reference iron standard and which was assigned a relative biological value (RBV) or potency of 100%. Three groups were used to assess each iron source using the different treatments of sorghum. This was done for ten days. After the 10 days the animals were bled from the tail vein for the determination of haemoglobin. Haemoglobin repletion was measured for the different dietary levels of iron. A linear regression model was used to calculate the slopes for haemoglobin gain against dietary iron concentration for each diet. The percentage of available iron was then obtained as the ratio of the slope of the sample and the slope of the reference iron sulphate.

c) Zinc Availability.

Zinc availability was determined by a method similar to that described by Field and Oace (1981). 13 diets were formulated, using egg white for the reference diet, with added amounts of zinc sulphate in different amounts to provide a standard curve. Details are given in Table 18. All the sorghum diets contained the same level of zinc namely 12 ppm.

Table 16. Zinc Availability: Composition of Diets[a](Dry Weight)g.

Sample Description	Quantities							
	Diet	Eggwhite	Sorghum	Oil	Minerals	Vitamins	Cellulose	Starch
Lugugu-Ungerminated	500	104	212	50	25	5	25	79
Lugugu-Germinated	500	104	212	50	25	5	25	68
5 DX-Ungerminated	500	104	291	50	25	5	25	0
5 DX-Germinated	500	104	234	50	25	5	25	57
Udo-80%-Ungerminated	500	104	176	50	25	5	25	115
Udo-bran-Ungerminated	500	104	159	38	19	4	21	155
Udo-whole-Ungerminated	500	104	209	50	25	5	25	82
Udo-whole-Germinated	500	104	179	50	25	5	25	112

[a]The basal diet used for reference amounted to 500 g dry weight. It was composed of: Egg white 104 g, Corn oil 25 g, Mineral mixture 25 g and Vitamin mixture 5 g (Forsum *et al*. 1973); Cellulose 25 g and Corn starch 291 g. 5 levels of zinc, namely 3, 5, 7, 9 and 11 ppm Zn, from $ZnSO_4 \cdot 7H_2O$, were added to the 5 basal diets which were used for reference.

104 Spragues Dawley, male weanling rats, aged 21 days were weighed and divided into 13 comparable groups according to their weights. Each group had 8 rats and each group was offered one of the experimental diets. The rats were individually housed in stainless steel cages at 28°C, 40% relative humidity and 12 hours light/12 hours darkness. The diets and deionized water were fed "ad libitum" for 5 days which were enough for serum zinc changes. The zinc content of the diets was determined by atomic absorption spectrophotometry. At the end of the experiment, the rats were lightly anaesthesized and blood samples withdrawn by cardiac puncture. Serum zinc concentration was determined by atomic absorption spectrophotometry after precipitation with trichloroacetic acid (50 g/l).

Serum zinc content was plotted against zinc content in the reference zinc sulphate diets. This gave a linear response which was used as the standard curve for calculating zinc availability. Serum zinc levels in the rats fed the sorghum test diets gave the corresponding level of zinc available from the sorghum and this was expressed as a percentage of 12 ppm Zn (dietary total zinc level).

4.6.3 Human Enzyme-Inhibitors

(a) Human trypsin and chymotrypsin inhibitor activity.

These were determined by the method described by Krogdahl and Holm (1981) whereby human pancreatic juice was collected from the duodenum at the mouth of the pancreatic duct by medical personnel. The juice was handled and stored till ready for use as described by Krogdahl and Holm (1979). The sorghum was finely ground and extracted and inhibition of human chymotrypsin measured according to Krogdahl and Holm (1979).

(b) Alpha Amylase Inhibitor Activity.

The samples were ground in a Wiley mill equipped with a No. 20 screen. The flour was extracted by mechanical stirring in a 0.02 M phosphate buffer, pH 6.9 for 2 hours at room temperature and centrifuged at 10.000xg for 30 minutes at 4°C. The supernatants were heated at 70°C for 10 minutes, centrifuged under the same conditions and tested for alpha amylase inhibitor activity as described by Granum and Whitaker (1977).

4.7 Dietary Bulk Determination

The flour and distilled water were mixed in a glass beaker covered with aluminium foil and heated in a boiling water bath to reach a cooking temperature of 95°C within 10 minutes and then kept cooking for 15 minutes. The gruel was left at room temperature (22°C) to cool. Gruels were prepared from either ungerminated or germinated flour, or ungerminated flour mixed with 5 to 10% germinated flour added before or after cooking.

4.7.1 Viscosity measurements

Viscosity measurements of the gruels in the laboratory were done on a Haake Rotovisco Viscometer model RVI with an SCII profiled measuring system (made by Gebruder Haake, Karlsruhe, West Germany) at a shear rate of 54 rpm. Measurements were taken at 40°C. A Brookfield Viscometer (Brookfield Engineering Laboratory, Stonghton, MA, USA) was used for field work in Tanzania.

4.7.2. Sensory Evaluation of Ungerminated and Germinated Sorghum Gruels

Seven samples were tested which included the 4 sorghum varieties, germinated and ungerminated except Udo which missed out the germinated sample. All samples were prepared as porridges of similar consistency (semi-fluid) which meant that ungerminated porridges had about 10% concentration while germinated porridges had about 20% concentration of solids.

The studies at the Swedish Food Institute (SIK) in Göteborg, Sweden, used an expert panel of 7 trained members (who had never seen or tasted sorghum, but were familiar with descriptive sensory method). The panel evaluated six texture sensory properties of the samples of porridge. Rating tests were done on texture evaluating: gelliness, graininess, sandiness and thickness (cold and warm). A scale similar to the Hedonic scale rating 1-10, was used (Indian Standard IS-6273, Part II-1971 (1972), Sidel and Stone (1976) for scoring the attributes.

In each session each judge evaluated all seven samples, presented in random order, differently for different judges. For practical reasons difficulty in keeping the serving temperature constant at 50°C for more than four samples at a time, the samples were presented 4 and 3 at a time with an intermission after the first four. The samples were evaluated both warm (50°C) and cold after chilling down to room temperature (22°C). All evaluations were done in 4 replicates.

Work in Tanzania involved selecting a Panel of workers at the Tanzania Food and Nutrition Centre, Dar-es-Salaam, screening them and selecting 7 who passed the screening tests on basic tastes after Indian Standard IS:6273 Part I 1971 (1972). This panel guided the formulation of weaning formulae for village level testing at Luganga village. Food acceptance studies used a consumer panel, whose reactions were obtained by personal interviews.

4.7.3 Luganga Village Study

(a) Location and Background. After demonstrating the amylolytic ability of germinated sorghum flour to reduce the viscosity of thick porridges, the flour malt was termed "POWER FLOUR" and this concept was used in its promotion at village level.

The work was carried out at Luganga village in Pawaga division which is part of Iringa Rural District within Iringa region. The village is situated about 40 kilometers north-west of Iringa town on the road to Itunundu.

Luganga village is located near the Little Ruaha river which is the local source of water. It is a typical Ujamaa village which was about 8 years old. The inhabitants had been moving into the village from surrounding areas and settling down over the period. The population had 250 families and 1300 people, increasing at about 3% per year. Social services included a dispensary with a Mother Child Health (MCH) Unit, a primary school and a village shop. Administration is provided by the village council under the leadership of the political party (Chama cha Mapinduzi). This system was effectively used to organize and mobilize the villagers during our study.

The major crops grown were maize, millets, sorghum and rice under irrigation near the river. Legumes (cowpeas and beans), fruits and vegetables (pawpaw, guava, spinach and a variety of wild leafy greens). Oil seeds (groundnuts, simsim and sunflower) were also grown. Livestock (cattle, goats and sheep) were also kept. Data from the district head office (Iringa) showed that the major sources of income were crops (46%), livestock (30%), agricultural labour (6%) and others (18%).

The village was in a food deficient area during the dry season as its agricultural system had not been fully developed yet. Most food produced was consumed in the household, some was stored for off season use, while some millet and sorghum was sold for cash. However, cereals were widely used for making malted local beer.

Weaning food practices observed from interviews with 40 mothers, indicated that 90% of those interviewed breast fed for over 1 year, while 50% went to two years and a smaller percentage, up to 3 years. This pattern has been observed elsewhere in Tanzania (Kimati 1983, Bantje and Yambi 1983).

Infants were usually fed on thin watery gruels made from maize, millet or sorghum flour and milk was at times added. Introduction of food, other than milk started as early as the first month depending on the milk production by the mother. As children grew older even before they reached one year, separate weaning foods were not prepared, but they were forced to eat from the family pot in competition with the older children. A better variation was the practice of taking a small portion of stiff porridge from the family pot, thinning it down with gravy or milk and feeding it to infants. It was therefore obvious that weaning foods in the village were bulky preparations with low energy and nutrient density.

The nutritional status of children attending the MCH center as indicated by weight for age is summarised in Table 17. As indicated in Table 17, from 2 up to 6 months of age most of the children in the study had almost normal weight for age above 90% of the standard. From 6 months up to 24 months, on average, about 68% of the children were classified as underweight (below 80% of weight for age) indicating that there existed nutritional problems in the village of Luganga. This observation tallied with average nutritionally at risk statistics for Tanzania and Iringa Region (Tanzania Food and Nutrition Centre 1983).

Table 17. Weight for Age Data from MCH Records at Luganga Dispensary

Number of children	Age (months)	Average weight (kg)	Standard weight[a] (kg)	Percentage of "Standard" weight
5	1	3.6	4.3	84
7	2	5.9	5.0	118
18	3	6.2	5.7	109
22	4	6.5	6.3	103
17	5	6.8	6.9	99
15	6	7.1	7.4	90
20	7	7.1	8.0	89
16	8	7.5	8.4	89
19	9	7.4	8.9	84
10	10	7.5	9.3	81
6	11	7.8	9.6	81
7	12	8.2	9.9	83
16	13	8.4	10.2	87
9	14	8.2	10.4	79
6	15	8.1	10.6	76
7	16	8.6	10.8	80
4	17	9.5	11.0	86
5	18	8.7	11.3	77
8	19	7.2	11.5	63
6	20	8.1	11.7	69
4	21	9.4	11.9	79
5	22	8.5	12.1	70
5	23	10.4	12.2	85
5	24	9.1	12.4	73

[a] The "Standard" weight used for comparison is based on the Harvard standard which has been adapted for Healthy Tanzanian children as recommended by the Tanzania Food and Nutrition Centre (1977), boys and girls combined.

40 households (which were 20% of all the households in the village) were selected at random to represent all the village adminstrative cells. Young children were selected from each household and their weights were recorded monthly for 10 months. The mothers volunteered to feed their children with thick (maize or sorghum) porridge, thinned down by the addition of hygienically prepared germinated maize or sorghum flour.

The study was begun when there was a food shortage in the village in February 1983. By mutual agreement between the villagers and the research team, the most readily available food items, namely maize grain or flour and groundnuts from the village shop, town market or households were used.

b) Acceptance of Bulk Reduced Weaning Porridge.

The aim of the study at Luganga village was to determine acceptance of bulk reduced gruels by mothers readiness to use the technique and actual food intake by young children.

The bulk-reduced weaning diet was prepared as follows: thick maize porridge containing 5% groundnut flour was cooked in a large iron pot by heating over a charcoal stove to boiling and was boiled for about 20 minutes. The cooked porridge was cooled to about 40°C, 5% (of total amount of flour) germinated sorghum (Lugugu) flour was added and stirred for 5 minutes thoroughly when the porridge thinned down to child feeding consistency.

(i) Acceptance of Bulk Reduced Porridge by mothers. Since young children usually eat what they are given it was desirable to use their mothers to test the acceptability of maize bulk-reduced porridge. Porridge initially containing 20% flour, was cooked for 30 minutes, cooled to 40°C, reduced in bulk by the germinated flour and served to 18 mothers attending the clinic. The mothers were asked to score their reactions on a Hedonic Scale score sheet. Smell, colour, taste, texture and readiness to feed this type of product to their children were the main parameters considered. The scale ranged from 5 (very good) to 1 (very bad) as described in the Indian Standard of 1972. The research team interviewed mothers who were illiterate and helped in marking the scores. This could have affected the final scores, though the mothers were asked to be honest and avoid reacting, just to please the interviewer.

(ii) Acceptance of Bulk Reduced Porridge by Preschool Children.

Initially group feeding was carried out at the village dispensary. Each child was served a weighed portion of maize porridge prepared as described before, using a "Salter" top balance scale. The very young children unable to feed themselves were fed by their mothers or caretakers, but the older children were left to eat on their own under the supervision of their mothers. In all cases, care was taken not to force the food on the child. If more food was wanted by the child, this was served in a weighed portion. After finishing the meal, all left-overs if any, were weighed and recorded. The recorded served amounts, minus the left-overs gave the food intake during the meal.

This preliminary work was done for 3 days in the months of March and April each and was taken as a demonstration and familiarization of the dietary bulk reduced gruel to the mothers, children and the research team. All concerned gained experience in preparing the gruels, measuring food intake by the children and keeping accurate records in readiness for detailed food intake studies later.

(c) Adoption of "Power Flour" by Mothers in Households.

The acceptance and use of power flour in the household was recorded by mothers whose children participated in the food intake study and lasted for a period of three months (April, May and June 1983). The mothers were just asked to record every time they used "power flour" in making porridge for their children. For those who did not keep records, the research team used the recall method monthly. Most mothers made their own germinated flour or borrowed from their neighbours.

(d) Reduction of Dietary Bulk of Improved Home-Made Weaning Foods.

Observations in Luganga village had indicated that mothers tended to wean their children using simple cereal gruels with minimum supplementation. However the food crops produced locally could be used to make double or even multimixes of weaning foods at home. Local recipes were collected, evaluated using food tables and improved recipes were prepared in the laboratory at the Tanzania Food and Nutrition Centre in Dar es Salaam. Germinated sorghum flour (Lugugu) was added to the cooked weaning foods and bulk reduction determined using the Brookfield Viscometer.

The following preparations were used to study the effect of "power flour" on weaning food multimixtures. Maize flour porridge was prepared with either groundnuts, legumes and green vegetables. The groundnuts were first roasted and pounded into flour. Beans and peas were cooked separately and mashed thoroughly. Cassava and pumpkin leaves were pounded into a paste, then cooked. The samples were cooked on an electric hot plate till judged ready, then mixed and mashed or mixed into a smooth consistency weaning gruel. 5 g germinated sorghum (Lugugu) flour were added to the gruel mixtures after cooking and cooling to lower the viscosity.

(e) Weaning Food Intake by Preschool Children.

In household food intake measurements, the same procedure as already outlined was followed. In studies to compare porridge with and without "power flour", the following procedure was followed once each month. On the first day, in each test household, the children were served with porridge containing 5% flour (initial wet weight). On the second day, they were given a 20% flour content porridge thinned with 5% "power flour" (germinated white sorghum-Lugugu or germinated maize). On the third day, the children were served porridge containing 20% flour without "power flour". All the flour used contained 5% groundnut flour as a supplement flavouring agent since no sugar was added. The porridge was served between 9.00 and 10.00 in the morning which meant that the younger children would have eaten something at least. The final test group had 14 girls and 18 boys.

It is important to note that a limited food shortage occurred in the village from September 1983 to February 1984, which was the height of the dry season and the long rains respectively. During the food intake studies the research team provided most of the maize flour, groundnut flour and the "power flour". Absenteeism in some households occurred for a variety of reasons such as travel, early work in the field or attendance at the hospital.

4.8 Statistical Methods

Most of the analytical results required no statistical analysis as the methods used single or duplicate samples. The analytical techniques used were accurate enough to indicate differences.

The rat bioassay results were statistically analysed using Duncans test (Duncan 1955) to test levels of significance.

In vivo iron availability by the slope ratio technique was statistically treated following a general linear models procedure (Freund and Littell 1981, Searle 1971 and Rao 1973), using a computer programme at the Göteborg Data Centre-Sweden.

Statistical levels of significance in the food intake studies were determined using Wilcoxon's non-parametric method with signed rank test as described by Colton (1974).

CHAPTER V

5. RESULTS

In Chapter IV, details of preparing the material for investigation were given with emphasis on processing which included germination, traditional and abrasive dehulling as well as milling. Consequently only minimal reference is made to these topics in this chapter.

The experimental results are presented in tables. Often data reduction, showing mainly the means, was used with an indication of the number of observations made and relevant statistical deviations. Figures were also used, where applicable and explanatory footnotes given when necessary for clarity.

5.1 Chemical Composition of Whole, Dehulled, Germinated and Ungerminated Sorghum Flour.

This section covers results of proximate analysis and details of the major components which influence sorghum nutritional value. The amino acid patterns of the protein was used as an indicator of protein quality. Fatty acid content of the oil emphasised the essential fatty acids which are important in public health. Dietary fibre and uronic acid content, minerals and vitamins of major nutritional importance in Tanzania were also determined. Factors, such as tannins and phytin-phosphorus which influence nutrients availability featured strongly in this study. Aflatoxins, which are a potential health hazard, were determined as a precautionary measure. The results are hence presented in the following subsections.

5.1.1 Proximate Analysis

Results of proximate analysis of whole flour and traditional and abrasive dehulled samples are presented in Table 18.

Table 18. Proximate Analysis of Ungerminated and Germinated Whole and Dehulled Sorghum Flour (wet and dry basis).

	Moisture (%)	Energy (kcal/100g)		Protein[a)] (%)		Fat (%)		Ash (%)	
	wet	wet	dry	wet	dry	wet	dry	wet	dry
Whole flour[b)]									
ET 35 -ungerm.	11.5	406	454	11.3	12.6	3.7	4.1	1.9	2.1
germ.	13.7	419	486	10.4	12.1	3.2	3.7	1.3	1.5
5 DX -ungerm.	11.8	406	459	10.6	12.0	3.1	3.5	1.6	1.8
germ.	11.3	398	450	10.8	12.2	2.7	3.1	1.5	1.7
Lugugu ungerm.	10.3	423	470	11.7	13.0	3.7	4.1	1.6	1.8
germ.	12.8	404	465	11.4	13.1	2.8	3.2	1.5	1.7
Udo -ungerm.	11.4	396	448	9.9	11.2	2.6	2.9	5.2	5.9
germ.	11.5	397	449	10.2	11.5	2.4	2.7	1.6	1.8
80% extr. rate[b)]									
ET 35 -ungerm.	11.4	424	479	11.3	12.8	-[c)]		1.8	2.0
germ.	12.7	413	475	10.9	12.5	-		1.3	1.5
5 DX -ungerm.	12.0	405	462	9.6	10.9	-		1.7	1.9
germ.	11.4	422	477	10.8	12.2	-		1.2	1.4
Lugugu ungerm.	10.2	417	467	11.4	12.8	-		1.9	2.1
germ.	12.7	421	484	11.7	13.5	-		1.7	2.0
Udo -ungerm.	11.2	402	454	9.7	11.0	-		1.8	2.0
germ.	11.1	420	475	10.2	11.5	-		1.4	1.6
Traditionally dehulled[d)]									
ET 35 -ungerm.	10.7	419	469	10.7	12.0	1.4	1.6	0.8	0.9
germ.	11.3	409	462	10.3	11.6	1.4	1.6	1.0	1.1
Lugugu ungerm.	10.3	414	464	11.8	13.2	1.5	1.7	1.3	1.5
germ.	12.7	425	489	11.6	13.3	1.3	1.5	1.3	1.5
Udo -ungerm.	10.2	399	443	10.0	11.1	1.6	1.8	2.2	2.4
Abrasive dehulled[d)]									
ET 35 -ungerm.	11.5	404	457	10.2	11.5	2.3	2.6	1.1	1.2
5 DX -ungerm.	9.4	409	450	11.1	12.2	2.0	2.2	1.1	1.2
Lugugu ungerm.	10.1	408	449	11.4	12.5	2.4	2.6	1.3	1.4
Udo -ungerm.	10.8	413	463	10.0	11.2	2.1	2.4	3.2	3.6

a) (N x 6.25) = Crude protein b) laboratory milled
c) not determined d) village hammer milled
The dry weight basis data is just given for comparison.

The high moisture content in the grain and flour products were reduced by oven drying to about 11% for safe storage. The energy level ranged from 396 kcal/100g for whole flour ungerminated Udo to 425 kcal/100g for traditionally milled germinated Lugugu. Neither the dehulling nor the germination procedure caused any appreciable change in the energy content of the sorghum varieties.

Crude protein content (Kjeldahl-N x 6.25) ranged from 9.9% for Udo ungerminated to 11.7% for Lugugu ungerminated. For the whole flours, the ET-35 variety was the only variety that showed a slightly lower crude protein content after germination. Dehulling also influenced the crude protein value in the ET-35 variety and on dry basis the whole flour value of 12.8% was decreased to 12.0% after traditional dehulling and to 11.5% after abrasive dehulling.

The fat content was higher in the low-tannin varieties, 3.7% in ungerminated whole flour compared to 3.1 and 2.6% in the high-tannin varieties respectively. The germination procedure decreased the fat content in all varieties by 6-24%. Abrasive dehulling lowered the fat content by 19-38% and traditional dehulling by 38-62%.

The ash content in the ungerminated whole flour varied from 1.6% in Lugugu to 5.2% in Udo. The germination procedure lowered the ash content especially in Udo to 1.6%. Both traditional dehulling and abrasive dehulling decreased the ash content.

5.1.2 Amino Acid Composition

(a) Whole Milled Sample

The amino acid pattern for the whole sample of ungerminated and germinated sorghum varieties is summarized in Table 19.

Table 19. Amino Acid Composition of Whole Milled Sample Flour from Ungerminated and Germinated Varieties of Sorghum Grain.

(mg/gN)	Lugugu		Udo		ET 35-1		5 DX	
	Ung.	G.	Ung.	G.	Ung.	G.	Ung.	G.
Lys	109	123	129	138	123	129	125	137
His	120	121	135	136	117	115	116	129
Trp	65	66	68	65	70	72	66	68
Arg	236	191	235	229	210	194	205	220
Asp	406	415	434	429	418	420	469	468
Thr	206	221	214	217	210	208	217	215
Ser	276	269	286	284	277	276	287	288
Glu	1291	1256	1293	1271	1268	1276	1316	1315
Pro	579	555	562	564	558	565	538	535
Gly	182	185	200	197	193	191	203	204
Ala	576	589	594	571	577	616	599	588
Val	303	311	308	317	315	323	328	336
Cys	98	95	90	95	100	102	98	95
Met	88	88	107	93	76	73	90	87
Ile	252	255	254	261	245	246	265	259
Leu	821	841	841	821	845	814	886	833
Tyr	245	241	251	247	238	244	243	249
Phe	329	330	327	328	322	326	346	340
Crude protein (Nx6.25)	11.7	11.7	9.8	10.2	11.3	10.8	10.4	10.8
Chem. score[a)]	0.32	0.36	0.38	0.41	0.36	0.38	0.37	0.40

[a)]Lysine-limiting amino acid in all samples.

Considering lysine, which is the most limiting essential amino acid, the low-tannin types (Lugugu and ET 35) averaged 116 mg/gN of lysine while the high-tannin varieties (Udo and 5 DX) averaged higher, with 127 mg/gN in the ungerminated samples.

In all the varieties, germination increased the lysine value by 12.8% in Lugugu, 9.6% in 5 DX and 7.0% in Udo. ET 35 had a marginal increase of 4.9%.

The chemical scores done by the FAO/WHO (1973) recommended method, confirmed that lysine was limiting with scores ranging from 0.32 to 0.41. The low-tannin varieties had higher scores than the high-tannin types. The germination procedure increased the chemical score in all varieties, corresponding to the increase in lysine content, thus indicating a higher protein quality. Changes in other essential amino acids due to germination were below 5% except the methionine value in Udo which decreased by about 13% after germination.

(b) Traditionally Dehulled Sorghum Flour.

The amino acid content of ungerminated and germinated flour products traditionally dehulled are presented in Table 20.

The lysine content was slightly higher after germination in the low-tannin varieties. In ET 35, the lysine value was 12% higher and in Lugugu, 5% higher. The chemical scores were, however, lower in the traditionally dehulled flour compared to the whole flour respectively due to lower lysine values.

Table 20. Amino Acid Composition of Traditionally Dehulled Sorghum Flour.

	(mg/gN) Lugugu		Udo	ET 35-1	
	Ung.	G.	Ung.	Ung.	G.
Lys	88	92	102	91	102
His	120	113	110	120	117
Trp	60	62	66	66	66
Arg	185	177	193	178	186
Asp	394	413	405	394	424
Thr	203	201	205	198	204
Ser	269	266	269	269	277
Glu	1263	1305	1302	1404	1352
Pro	633	589	571	615	570
Ala	597	566	572	608	601
Val	303	301	304	318	319
Cys	96	96	90	100	100
Met	84	82	87	79	74
Ile	254	254	247	257	273
Leu	893	845	816	930	912
Tyr	248	238	246	233	255
Phe	339	329	311	345	348
Crude protein (Nx6.25)	11.8	11.5	10.4	10.6	10.3
Chemical score[a]	0.26	0.27	0.30	0.27	0.30

[a] Lysine-limiting amino acid in all samples

(c) Abrasive Dehulled Sorghum Flour.

The amino acid content of abrasive dehulled flour is presented in Table 21.

Table 21. Amino Acid Composition of Abrasive Dehulled Ungerminated Sorghum Flour[(a)].

	(mg/gN) Lugugu	Udo	ET 35-1	5 DX
Lys	101	116	109	114
His	129	124	127	132
Trp	62	66	68	68
Arg	193	206	199	183
Asp	428	424	433	450
Thr	209	207	208	195
Ser	258	257	265	245
Glu	1299	1300	1339	1270
Pro	550	539	552	514
Gly	182	174	176	160
Ala	581	582	574	545
Val	326	334	326	311
Cys	96	90	98	96
Met	67	77	65	70
Ile	270	260	271	261
Leu	895	841	913	858
Tyr	268	258	244	240
Phe	361	329	346	335
Crude protein, (Nx6.25)	10.9	9.9	10.3	10.9
Chemical Score[b)]	0.30	0.34	0.32	0.34

[a)]Extraction rate of 90%. [b)]Lysine-limiting amino acid in all samples.

Compared to whole flour, the lysine values in mg/gN were lower in the abrasive milled samples. The chemical score were therefore also lower. Compared to the traditionally dehulled flour, the abrasive dehulling did not reduce the lysine content to the same extent.

5.1.3 Fatty Acids

The findings on the fatty acids content are summarised in Table 22.

The seeds were germinated for 72 hours instead of the usual 48 hours to allow more time for germination physiological changes, that might produce noticeable changes in the fatty acid content. In all the varieties, oleic and linoleic acids were predominant with a total amount of about 80% of the seeds fatty acid content. Udo ungerminated had the highest oleic acid value with 44.5% while Lugugu germinated had the lowest with 27.7%. However, Lugugu ungerminated had the highest linoleic value with 51.7% while Udo ungerminated had the lowest with 36.2%.

The method used is very accurate (Folch et al. 1957), within 1-2%, so differences of more than 5% were treated as significantly different. The germination procedure did not cause any significant change in the pattern of oleic and linoleic fatty acids. However, considering the total content of fatty acids, germination decreased the fatty acid content in all varieties: ET 35 by 34.6%, 5 DX by 30.0%, Lugugu by 25.0% and Udo by 20%.

Table 22. Fatty Acid Content as Percentage of Whole Seed Fatty Acids in Ungerminated and Germinated[a] Whole Sorghum Flour.

Fatty acids	Fatty Acid Content (%)							
	ET 35		5 DX		Lugugu		Udo	
	Ungerm.	Germ.	Ungerm.	Germ.	Ungerm.	Germ.	Ungerm.	Germ.
C 16:0 Palmitic	13.9	14.3	14.6	14.7	15.1	14.6	14.8	15.1
C 16:1 Palmitoleic	0.7	0.7	0.7	0.7	0.7	0.7	1.0	0.7
C 18:0 Stearic	1.5	1.8	1.5	1.8	1.4	1.5	1.4	1.5
C 18:1 Oleic	41.4	39.4	31.8	31.0	28.8	27.7	44.5	42.8
C 18:2 Linoleic	41.1	41.2	50.0	49.3	51.7	51.6	36.2	36.0
C 18:3 Linolenic	2.2	3.1	2.2	2.9	3.1	3.9	3.1	4.2
mg fatty acid/g	25.6	16.8	19.6	14.0	23.5	18.2	19.6	15.7

[a] Germination for 72 hours.

5.1.4 Dietary Fibre and Uronic Acids.

(a) Dietary Fibre

The dietary fibre results are summarised in Table 23.

Table 23. Total Dietary Fibre and Undigestible Protein in Raw Sorghum Flour (%).

	Dietary Fibre	Undigestible Protein	Corrected Dietary Fibre
Whole Flour			
ET 35 -ungerm.	12.1	2.9	9.2
germ.	13.0	2.8	10.2
5 DX -ungerm.	19.9	8.3	11.6
germ.	19.8	8.2	11.6
Lugugu-ungerm.	11.2	4.2	7.0
germ.	11.5	4.7	6.8
Udo -ungerm.	18.9	8.9	10.0
germ.	17.9	7.7	10.2
Traditional Flour (80% extraction)			
ET 35 -ungerm.	9.2	4.2	5.0
5 DX -ungerm.	17.1	8.3	8.8
Lugugu-ungerm.	10.4	5.7	4.7
Udo -ungerm.	15.3	7.8	7.5

The total dietary fibre in the whole flour ranged from 11.2% in ungerminated Lugugu to 19.9% in ungerminated 5 DX. The amount of undigestible proteins was significantly higher in the high-tannin varieties, about 8%, compared to about 4% in the low-tannin varieties. The corrected dietary fibre which did not include undigestible protein ranged from 6.8% in germinated Lugugu to 11.6% in 5 DX, the high-tannin varieties still having slightly higher values. Taking into consideration the accuracy of the method, there was no significant difference between the germinated and ungerminated whole flour in uncorrected dietary fibre and undigestible protein. The same applied to corrected dietary fibre.

Traditional dehulling reduced the corrected dietary fibre content considerably, in the low-tannin varieties by about 40% and in the high-tannin varieties by about 20%.

(b) Uronic Acids and Neutral Sugars.

The uronic acids and neutral sugars content were examined in the variety Lugugu and the findings are presented in Table 24.

Table 24. Neutral Sugars and Uronic Acids in Ungerminated and Germinated Whole Flour of the Variety Lugugu (%).

	Arabinose[a)]	Xylose	Galactose	Glucose	Uronic acids
Lugugu-ungerm.	23	18	1	49	9
germ.	22	16	2	51	9
	Polysaccharides[b)]	Polysaccharides + Klason lignin			
Lugugu-ungerm.	7.4	10.0			
germ.	6.9	9.1			

[a)]Percentage of total amounts of neutral sugars and uronic acids.
[b)]Percentage of total dry matter.

Of the neutral sugars analysed, glucose was most abundant, 49% of total followed by arabinose 23% and xylose 18%.

As evident from Table 24 germination produced no significant change in arabinose, xylose, glucose and uronic acids. However, galactose increased in the germinated sample. There was a 7% decrease in polysaccharides and a 9% decrease in polysaccharides plus Klason lignin, in the germinated sample compared to the ungerminated seed.

5.1.5 Mineral Content

The mineral content of the whole flour, traditional flour and abrasive dehulled flour is given in Table 25.

Table 25. Mineral Content of Sorghum Flour (mg/100 g)

	Calcium	Phosphorus	Iron	Zinc
Whole Flour				
ET 35 -ungerm	17	370	3.4	2.5
germ.	12	347	3.2	2.1
5 DX -ungerm.	20	329	3.7	1.9
germ.	21	323	3.6	2.3
Lugugu-ungerm.	27	315	10.9	1.9
germ.	18	308	7.4	3.4
Udo -ungerm.	28	234	32.6	2.6
germ.	20	272	15.7	3.0
Traditionally Dehulled				
ET 35 -ungerm.	16	176	2.0	0.7
germ.	12	171	2.1	1.4
Lugugu-ungerm.	15	265	5.2	1.6
germ.	9	243	3.9	1.8
Udo -ungerm.	16	196	9.4	1.7
Abrasive Dehulled				
ET 35 -ungerm.	9	282	2.7	1.0
5 DX -ungerm.	11	239	3.8	1.4
Lugugu-ungerm.	8	270	4.3	1.9
Udo -ungerm.	8	230	15.0	1.5

The mineral content was affected by the germination procedure, both at laboratory and village level. Changes were also effected by the different dehulling methods.

The calcium content in the whole flour was decreased after germination, in ET-35, Lugugu and Udo and in the traditionally dehulled flour after germination, for ET-35 and Lugugu. Abrasive dehulling decreased the calcium content in all varieties of ungerminated flour, between 45 and 71%. The traditional dehulling method decreased the calcium content only in Lugugu and Udo by about 44%.

The phosphorus content was only affected by germination in two of the varieties, ET-35 with a slight decrease: in Udo there was a slight increase after germination. Abrasive dehulling decreased the phosphorus content significantly in all four varieties and traditional dehulling, even more, with a range in decrease of 16 to 52%.

The iron content was high in Lugugu with 10.9 mg/100 g and Udo with 32.6 mg/100 g in the ungerminated whole flour samples. The germination procedure which included washing with water considerably reduced the iron content in these two varieties. Both traditional and abrasive dehulling significantly decreased the iron content in all varieties.

The zinc content in the whole flour ranged from 1.9 mg/100 g in ungerminated 5 DX to 3.0 mg/100 g in germinated Udo. The germination procedure caused an increase in zinc content except in ET 35. Abrasive dehulling significantly reduced zinc content.

5.1.6 Vitamins

The vitamin content of the four varieties is summarised in Table 26.

(a) Thiamine. Thiamine ranged from 4.3 ug/g in ungerminated 5 DX to 6.5 ug/g in germinated Lugugu. The effect of germination was variety dependent. Thiamine content increased significantly by 11% in ET 35, 27% in Udo and a marginal increase in Lugugu after 48 hours of germination. However, the thiamine content decreased by 12% in 5 DX.

(b) Niacin. Niacin content ranged from 24.3 ug/g in ungerminated 5 DX, to 45.4 ug/g in ungerminated ET 35. There was an increase of niacin in all the varieties after germination except in ET 35 which decreased marginally, 5 DX increased by 36%, Lugugu 33% and Udo 18%.

Table 26. Vitamin Content of Whole Sorghum Flour (ug/g).

	Thiamine	Niacin	Pantothenic acid	Riboflavin	Vitamin C
Whole Flour					
ET 35 -ungerm.	4.4	45.4	2.6	0.4	
germ.	4.9	42.6	8.4	1.2	(0)
5 DX -ungerm.	4.3	24.3	2.6	0.4	
germ.	3.8	33.0	6.7	1.1	(0)
Lugugu-ungerm.	6.3	29.0	3.1	0.4	
germ.	6.5	38.5	9.3	1.2	(0)
Udo -ungerm.	4.9	31.9	1.8	0.5	
germ.	6.2	37.7	5.5	1.1	(0)

(c) Pantothenic Acid. Pantothenic acid showed the largest increase of all vitamins after germination and increased by 223% in ET 35, 200% in Lugugu, 206% in Udo and 158%in 5 DX. The low-tannin varieties ET 35 and Lugugu had slightly higher increments compared to the brown high-tannin types 5 DX and Udo.

(d) Riboflavin. Riboflavin showed a similar trend after germination as pantothenic acid, increasing the riboflavin content by 200% in both ET 35 and Lugugu while 5 DX and Udo had 175% and 120% increase respectively.

(e) Vitamin C. The vitamin C content was found to be zero by the method used.

5.1.7 Tannins

The tannin content of sorghum treated differently and expressed as catechin equivalents (%) is given in Table 27.

Table 27. Tannin Content[a] in Sorghum as Affected by Different Treatments.

Sample Treatment	Tannin Catechin Equivalent (%)[a]	
Variety	5 DX	Udo
As harvested	3.06	5.90
Acid washed[b]	2.25	4.00
Soaked in distilled water 24 hours	2.22	3.05
Germinated for 48 hours	2.15	2.10
Soaked in soda solution[c] for 24 hours at pH 9	1.43	2.30
Traditional dehulling	1.55	1.40
Abrasive dehulling	2.24	2.05

[a]As Catechin Equivalents, %.
[b]Washed three times in 0.1 M HCl.
[c]0.1 M $NaCO_3/NaHCO_3$ solution.

The low-tannin varieties Lugugu and ET 35, did not show any tannin content by the method used. The high-tannin varieties as harvested, had 3.1% tannin (5 DX) and 5.9% tannin (Udo), averaging 4.5%. Acid washing reduced tannin content in 5 DX by 27% while in Udo, the reduction was 32%. Soaking the grain overnight (16 hours) in distilled water reduced tannin content by 28% in 5 DX and 48% in Udo. The germination procedure used namely washing in distilled water, soaking overnight, germination in dark for 48 hours and washing twice, reduced tannin content by 30% in 5 DX and 64% in Udo. Soaking the grain in 0.1M soda solution for 24 hours reduced the tannin content by an average of 57%.

Traditional dehulling reduced the tannin content in both varieties to an average level of 1.5%. Abrasive dehulling was not as effective. The tannin content was reduced to a level of 2.1%, similar to the level after germination for 48 hours.

5.1.8 Phytin-Phosphorus

The phytin-phosphorus content of whole flour, traditionally decorticated flour and abrasive dehulled flour is summarised in Table 28.

Table 28. Phytin-Phorphorus Content in Sorghum Flour (mg/100 g).

	Whole flour		Traditionally Dehulled		Abrasively Dehulled
	Ung.	Germ.	Ung.	Germ.	Ung.
Low-Tannin					
Lugugu	284	274	189	200	204
ET 35	306	306	142	175	263
High-Tannin					
Udo	216	194	159		156
5 DX[a]	306	301			174

[a]This variety was too soft for traditional dehulling.

In the ungerminated whole flour, the phytin-phosphorus content was about 300 mg/100 g in three of the varieties except Udo with 216 mg/100 g. Germination only slightly decreased the values in all the varieties except ET 35.

On the other hand traditional dehulling significantly decreased the phytin-phosphorus content by an average of 40%, while abrasive dehulling averaged a 28% decrease.

5.1.9 Aflatoxin

Determination of aflatoxins content in composite representative samples of whole flour, traditionally dehulled flour and abrasively dehulled flour, both ungerminated and germinated, yielded negative results.

5.2 Nutrient availability

5.2.1 *In Vitro* Nutrient Availability

In vitro nutrient availability in the sorghum varieties was done on protein and iron. Protein digestibility was determined by digesting with bovine pepsin. Iron availability was obtained from the ionizable iron fraction after pepsin digestion of the sample.

(a) Protein Digestibility

The results of sorghum protein digestibility *in vitro* are summarized in Table 29.

The ungerminated raw flour averaged 85% protein digestibility in the low-tannin varieties (ET 35 and Lugugu), while the high-tannin varieties (5 DX and Udo) averaged lower with 59% digestibility. The germinated low-tannin varieties had 100% protein digestibility, an average improvement of 18%, while the high-tannin types had a low 60% digestibility.

The high-tannin varieties behaved differently during germination. 5 DX rose to only 69% protein digestibility, yet it was a sizeable improvement of 23% over the ungerminated sample. However, *in vitro* protein digestibility was not affected much in the variety Udo.

Table 29 Pepsin Digestibility of Raw and Cooked Whole Raw and Traditionally Decorticated, Cooked and Freeze Dried Sorghum Flour.

Sample	Digestibility %
Whole Raw	
ET 35 -ungerm.	88.0
germ.	100.0
5 DX -ungerm.	56.0
germ.	69.0
Lugugu-ungerm.	82.0
germ.	99.0
Udo -ungerm.	61.0
germ.	63.0
Trad. decorticated, cooked and freeze dried	
ET 35 -ungerm.	41.9
germ.	50.1
Lugugu-ungerm.	40.6
germ.	46.6

The traditionally dehulled, cooked and freeze dried low-tannin sorghum flour had in vitro protein digestibility reduced by almost 50% compared to the whole raw sorghum flour. Germination increased the digestibility by an average of 16% in the cooked flour samples.

b) In Vitro Iron Availability.

Findings on the in vitro iron availability content are presented in Table 30.

Table 30. Ionizable Iron in Sorghum Flour by *In Vitro* Method.

Diet	Total Fe (mg/100g)[a]	Ionizable Fe available (%)	(mg/100g)
Low-tannin			
Lugugu-ungerm.	5.38	48.8	2.63
germ.	5.88	38.9	2.29
ET 35 -ungerm.	2.80	55.8	1.56
germ.	3.02	49.7	1.50
High-tannin			
Udo -ungerm.	6.06	46.4	2.81
germ.	5.67	27.7	1.57
5 DX -ungerm. 1982	3.44	10.9	0.37
germ. 1982	3.50	21.1	0.74

[a]Sorghum grain acid washed (Sufian and Pittwell 1968).

Ionizable iron, as percentage of total iron averaged 53% in the ungerminated low-tannin varieties. In the high-tannin varieties Udo had 46% and 5 DX, 11% ionizable iron.

After germination there was a slight decrease in ionizable iron in the low-tannin varieties while the decrease was substantial in Udo, from 2.81 mg/100 g to 1.57 mg/100 g. On the other hand there was an almost 100% increase in ionizable iron in the 5 DX variety, after germination.

5.2.2 In Vivo Nutrient Availability

(a) Protein Digestibility and Biological Value

Two studies were done using rats in nitrogen balance and digestibility trials. The first one used dietary sorghum protein as the only protein source and the second included supplementation with casein and methionine.

(i) Nitrogen Balance Study in Growing Rats Fed Unsupplemented Sorghum Diets

Food Intake and Weight Change

The food intake per rat over the balance period of 5 days is given in Table 31.

Table 31. Food Intake of Cooked Sorghum Products and Weight Changes[1,2]

Variety	Food Preparation		Food Intake	Weight Change
			g	g
Casein control			52.3[a]	+15.3[a]
ET 35 white	Dehulled[3]	ungerminated	25.9[bd]	-1.2[b]
		germinated	28.1[bc]	+0.7[b]
Lugugu "	"	ungerminated	24.5[bd]	+0.1[b]
" "	"	germinated	25.9[bd]	-0.2[b]
5DX brown	Whole	ungerminated	23.7[d]	-0.6[b]
" "	"	germinated	30.5[c]	-0.4[b]
Udo "	"	ungerminated	25.1[bd]	-3.0[c]
" "	"	germinated	26.6[bd]	-1.6[bc]

1. During balance periods of 5 days. Values represent means of 6 animals.
2. Values within the same column followed by different superscripts are significantly different. ($P<0.05$)
3. Traditionally dehulled.

The food intake over the balance period for different sorghum diets was low and was only about half of the intake of the reference casein diet. The lowest intake was 23.7 g for 5DX ungerminated and the highest was 30.5 g for the same variety germinated, which was significantly different ($p<0.05$). In the other varieties germination did not improve food intake significantly.

The weight change over the balance period is also presented in Table 31. Nearly all rats on the sorghum diets lost weight and differed significantly from the control group which gained 15.2 g ($p<0.05$).

Ungerminated whole flour of Udo gave the highest weight loss of 3.0 g while a slight weight increase was recorded for the rats on the germinated dehulled ET-35.

Nitrogen Balance on Sorghum Diets

Nitrogen balance results on cooked and freeze-dried sorghum diets are summarised in Table 32.

Table 32. Nutritional Quality of Whole, Dehulled, Germinated and Ungerminated, Cooked and Freeze Dried Sorghum Flour[1]

		Traditionally Dehulled Flour				Whole Flour			
		ET 35		Lugugu		5DX		Udo	
	Casein	Ung	Germ	Ung	Germ	Ung	Germ	Ung	Germ
True Protein	99.4^{a}	91.7^{b}	92.0^{b}	91.2^{b}	93.1^{b}	46.9^{c}	45.0^{c}	12.5^{d}	28.2^{e}
Digestibility (%)	$\pm$ 0.6	$\pm$ 1.4	$\pm$ 0.9	$\pm$ 2.0	$\pm$ 2.0	$\pm$ 6.3	$\pm$ 5.8	$\pm$ 8.2	$\pm$ 5.9
	(n = 7)	(n = 6)	(n = 6)	(n = 6)	(n = 5)	(n = 6)	(n = 6)	(n = 6)	(n = 6)

1. Values within the same row followed by different superscripts are significantly different ($p<0.05$)

True Digestibility (TD) values of ungerminated whole flour were 46.9 % for 5DX and 12.5 % for Udo respectively (high-tannin varieties). After germination an increase was shown only in Udo up to 28.2 %. The low-tannin varieties, traditionally dehulled, had high TD values either ungerminated or germinated, averaging 92 %.

The Biological Value (BV) of the sorghum proteins in the dehulled

(ii) Nitrogen Balance on Supplemented Sorghum Diets

In this rat bio-assay the diets were balanced with 50 % casein nitrogen and fortified with 1 % methionine. In calculating the digestibility for the sorghum proteins in the diet, a 100 % absorption was assumed for the casein nitrogen (see Table 33).

Table 33. Nutritional Quality of Ungerminated and Germinated Whole Raw Sorghum Flour[1,2]

	Udo + 50 % N from Casein + 1 % Methionine		Lugugu + 50 % N from Casein + 1 % Methionine	
	Ung	Germ	Ung	Germ
True Digestibility of the Mixture (%) (TD1)	69.1[a]	83.1[b]	98.6[c]	97.9[c]
True Digestibility of the Sorghum Proteins assuming 100 % Absorption of the Casein Protein (%) (TD2)	38.7[a]	66.3[b]	97.2[c]	95.7[c]
Biological Value (%)	99.0[a]	88.2[b]	86.2[c]	83.4[d]
Net Protein Utilization (%)	68.6[a]	73.3[b]	84.9[c]	81.6[d]
Digestible Energy (%)	75.9[a]	79.8[b]	92.2[e]	91.3[c]

1. Mean of 5 rats
2. Values within the same row followed by different superscripts are significantly different ($p<0.05$).

Table 33 shows a high TD value for raw whole flour Lugugu, 97.2 % and 95.7 % for ungerminated and germinated samples, respectively. Ungerminated flour of the high-tannin variety Udo had a TD value of 38.7 % and a significantly higher digestibility value of 66.3 % after germination.

Biological Values (BV) differed significantly between the two varieties and treatments. Germination decreased Biological Value in both varieties.

The Nitrogen Protein Utilization (NPU) was higher in Lugugu than Udo mainly due to a higher TD value in Lugugu. Germination increased the NPU in the high-tannin variety Udo, but lowered it in Lugugu.

The Digestible Energy (DE) was higher in the low-tannin variety Lugugu than in high-tannin Udo. Germination increased digestible energy by 7 % in Udo while there was no difference after germination in Lugugu.

(b) Iron Availability in Rats

The uncooked sorghum diets in this study were nutritionally adequate except for their limited iron content, and the rats ate the feed and grew well. None of the diets contained as much iron as the 35 mg/kg recommended (NRC, 1974). The dose-response curves are presented in Figures 2 to 5 and iron availability, presented as relative biological value (RBV) is given in Table 34.

Fig. 2. Sorghum (Lugugu) dietary iron response. Regression lines and slopes.

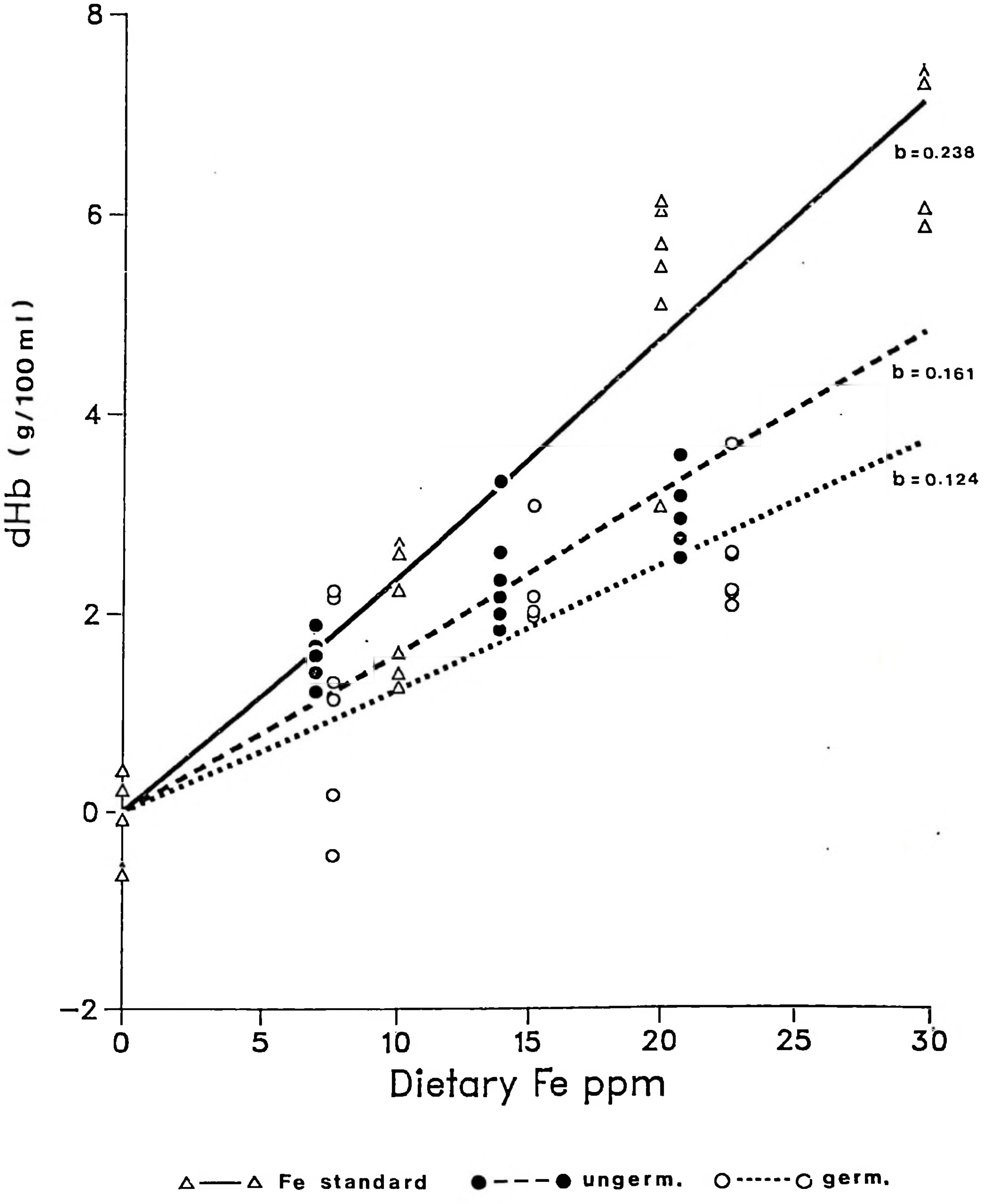

Fig. 3. Sorghum (ET-35) dietary iron response. Regression lines and slopes.

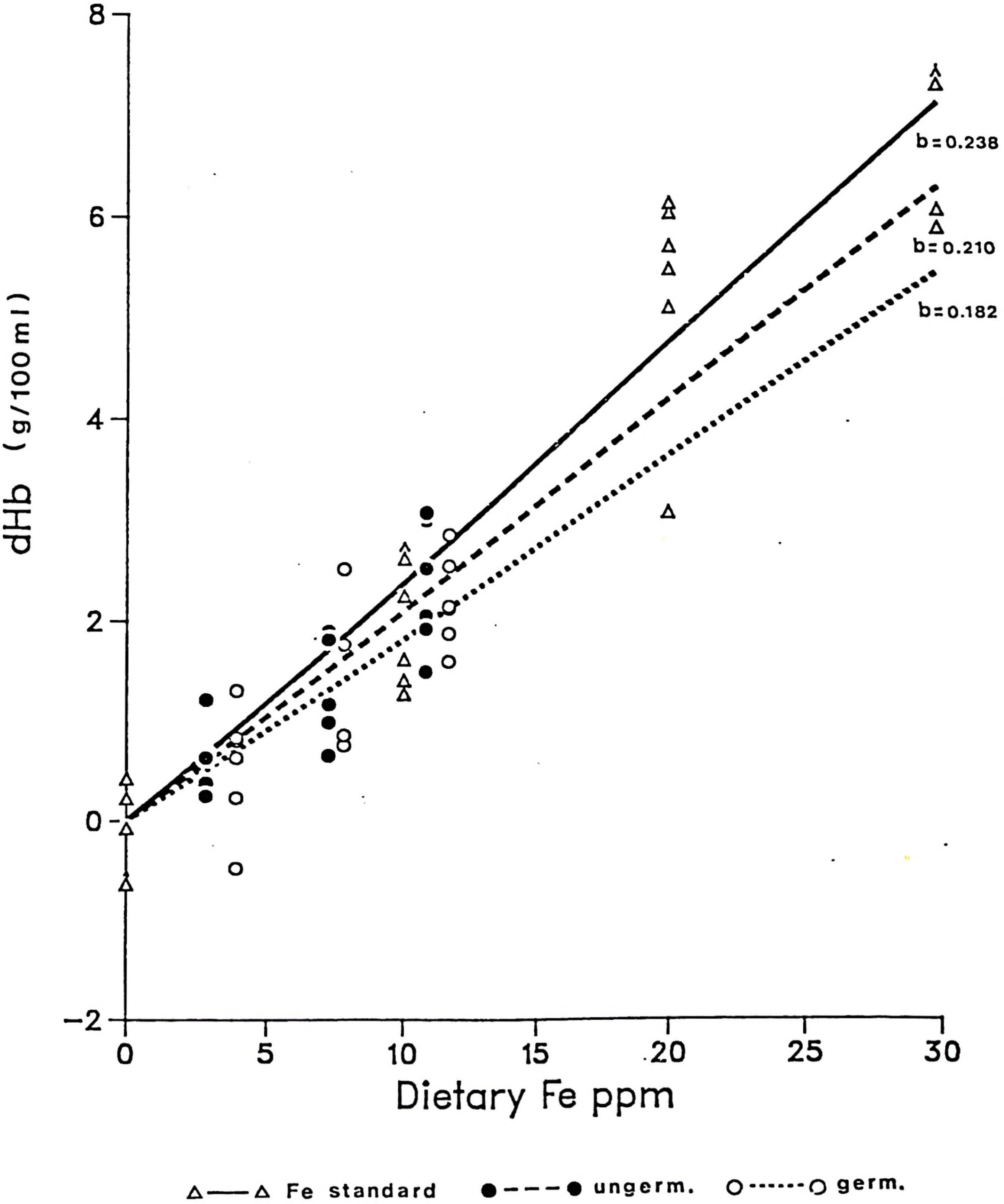

Fig.4. Sorghum (5DX) dietary iron response. Regression lines and slopes.

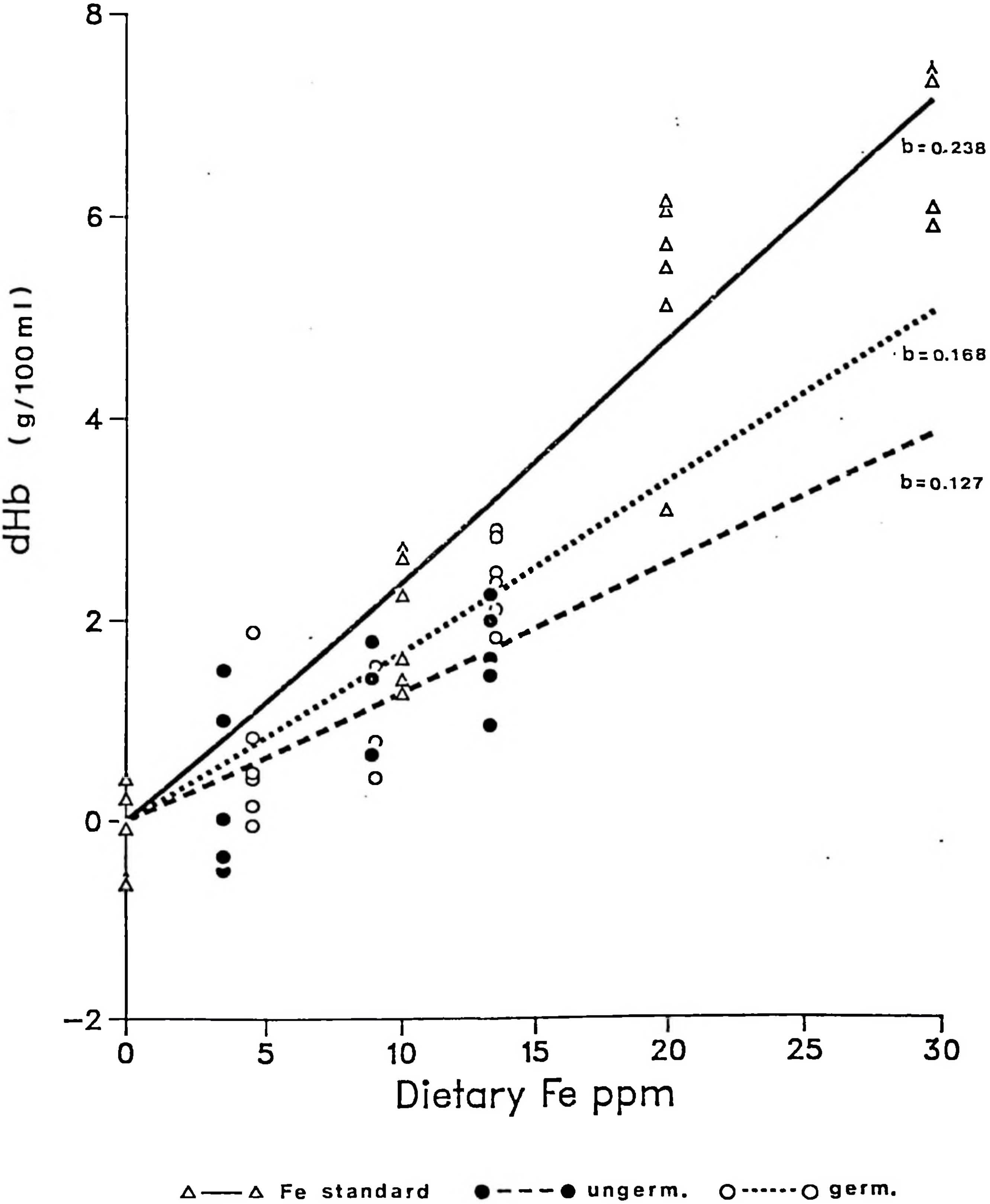

Fig. 5. Sorghum (Udo) dietary iron response. Regression lines and slopes.

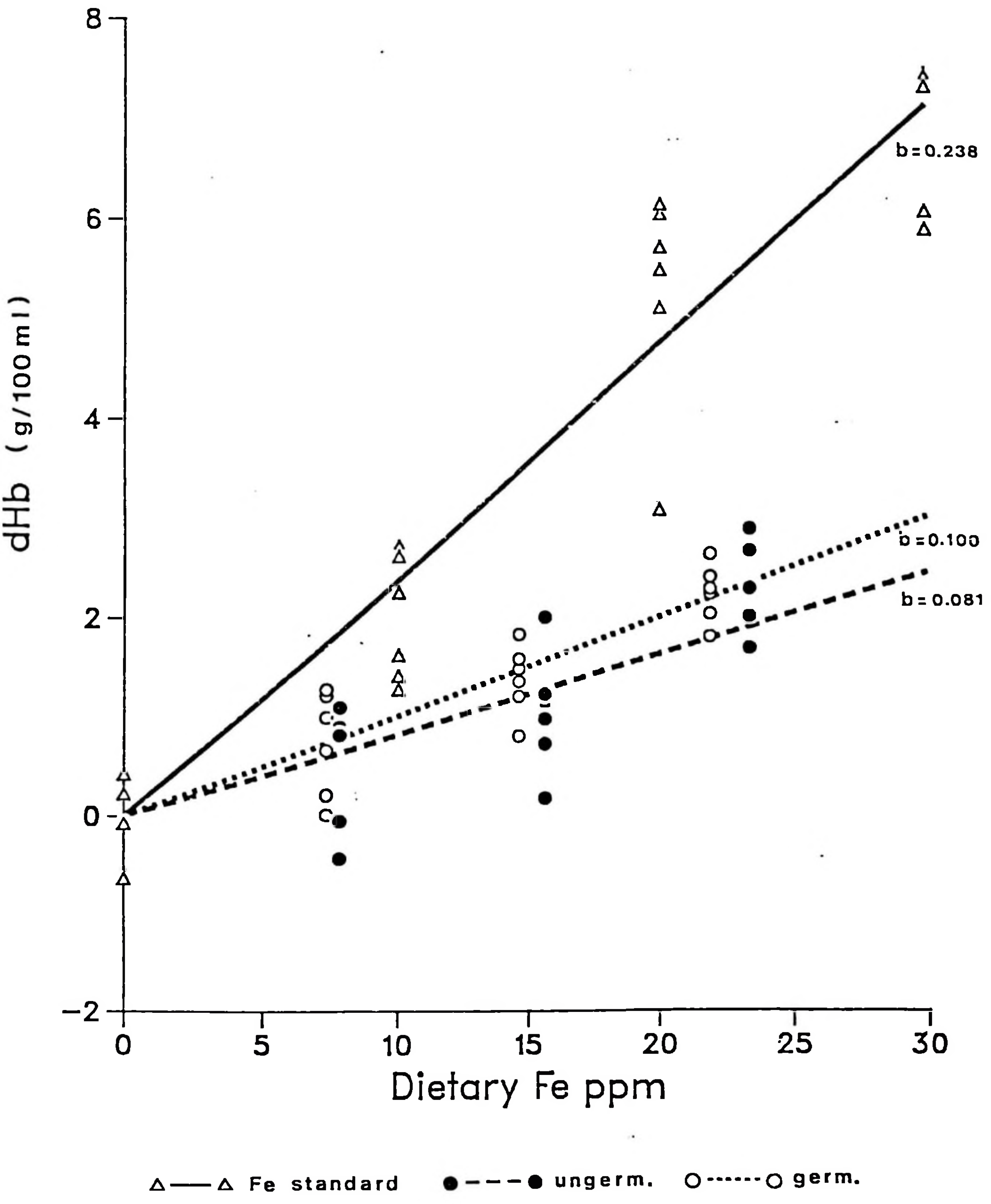

Table 34. Slope Estimates and Standard Errors of Regression Coefficients[a] and Relative Biological Value (RBV)[b] of Iron in Ungerminated and Germinated Whole Sorghum Flour

	Seed iron (Acid washed) mg/100 g	Slope ± S.E.	RBV mg/100 g	RBV %
Standard Fe		0.238 ± 0.008		100
Low-tannin				
Lugugu, ung.	5.38	0.161 ± 0.012	3.66	68
" germ.	5.88	0.124 ± 0.011	3.06	52
ET 35, ung.	2.80	0.210 ± 0.023	2.46	88
" germ.	3.02	0.182 ± 0.022	2.30	76
High-tannin				
UDO, ung.	6.06	0.081 ± 0.011	2.06	34
" germ.	5.67	0.100 ± 0.011	2.38	42
5DX, ung.	3.44	0.127 ± 0.019	1.82	53
" germ.	3.50	0.168 ± 0.019	2.49	71

a) Regression of hemoglobin iron gain on food iron concentration.

b) RBV is expressed as percent of that of iron in the standard diet containing ferrous sulfate which was assigned a value of 100 %.

From Table 34 the low-tannin variety Lugugu had a RBV value of 68 % and 52 % for ungerminated and germinated samples, respectively ($p<0.05$), while ET-35 had a RBV value of 88 % (ungerminated) and 76 % (germinated). The high-tannin variety Udo showed a low value of 34-42 %, while ungerminated 5DX had 53 % and 71 % after germination ($p<0.07$). All the test diets differed significantly from the standard ($p<0.05$).

Table 35. Test for Heterogeneity of Slopes Using Generalised Linear Models

Dependent Variable: (DHb)

Source	df	Mean Square	F-value	PR>F[a)]
Model	9	37.00	96.75	0.0001
Regression	1	224.66	587.54	0.0001
Heterogeneity of slopes	8	13.54	35.41	0.0001
Error	152	0.38		
R-square		0.85		
Contrast[b)]				
1-2 Lugugu	1		7.46	0.007
3-4 ET-35	1		1.12	0.293 ns
5-6 Udo	1		2.10	0.150 ns
7-8 5DX	1		3.42	0.07
Standard vis 1-2	1		96.33	0.0001
" 3-4	1		6.35	0.012
" 5-6	1		247.18	0.0001
" 7-8	1		40.86	0.0001

a) p value

b) Estimation of significant differences in slopes between ungerminated (1, 3, 5, 7) and germinated (2, 4, 6, 8) sorghum diets and between standard and test diets.

The linear model analysis of the combined data (Table 35) showed no significant departure from linearity of the regression lines and the high R-square value of 0.85 shows that the variation to a large extent is explained by the model.

No significant deviation was found for a common intercept of the slopes and all slopes were therefore adjusted to have a common intercept at zero dose.

The high F-value (35.41) for the heterogeneity of slopes shows that the slopes of the different sorghum diets and the standard diet are significantly different. These differences are shown in detail in the contrast test and significant differences are found for ungerminated and germinated Lugugu ($p<0.007$) and ungerminated and germinated 5DX ($p<0.07$). The standard slope is significantly different from all sorghum diets.

(c) Zinc Availability in Rats

Results of *in vivo* zinc availability using a rat bio-assay technique are presented in Table 36. The test diets have been described in Table 16.

Table 36. Availability of Zinc in Different Cooked Sorghum Preparations

Variety	Treatment	Tannins[a)]	Content of Zn	Availability of Zn[b)]	
		%	mg/100 g WW	%	mg/100 g WW
Lugugu	Dehulled[c)] ungerminated	0	2.53	43^a	1.09
Lugugu + tannic acid	" "	5.1	2.53	57^a	1.44
5DX	Whole "	2.3	1.87	33^a	0.62
5DX	" germinated	2.2	2.33	42^a	0.98
Udo	" ungerminated	5.1	2.60	51^a	1.33
Udo	" germinated	2.1	3.04	43^a	1.31
Udo	Dehulled ungerminated (extraction 80%)	2.2	3.09	59^a	1.82
Udo	Hull (20%) ungerminated		3.42	57^a	1.95

a) As catechin equivalents

b) Zn availability expressed as percentage of a zinc sulphate standard diet and values followed by different superscripts are significantly different ($p<0.05$).

c) Traditionally dehulled.

Table 36 indicates that there was no significant difference in zinc availability in all the samples. Zinc availability among the sorghum varieties ranged from 33 % of total zinc in germinated 5DX to 51 % in ungerminated Udo.

Germination caused a rise in the zinc content of the seeds but had no significant influence on zinc availability.

Adding tannic acid to the low-tannin variety Lugugu did not affect zinc availability. The high-tannin variety Udo had the same zinc availability either with or without the bran fraction.

(d) Inhibition of Human Enzymes by Raw Sorghum Extracts

(i) Amylase

The effect of whole sorghum seed extracts on human salivary amylase and pancreatic amylase are presented in Table 37.

Table 37. Inhibition (-) and Stimulation (+) of Different Sorghum Extracts on Human Salivary and Pancreatic Amylase

	Tannin Content (%)	Salivary Amylase (U[a])	Pancreatic Amylase (U)
Low-tannin			
Lugugu, ung.	0	-8.5	0
" germ.	0	-6.1	+1.2
High-tannin			
UDO, ung.	5.1	+6.9	+4.1
" germ.	2.1	+4.1	+2.4
5DX, ung.	2.3	+7.6	+6.1
" germ.	2.3	+9.7	+5.7

a) Amylase units. One amylase unit was defined as an increase of 1.0 in A 1 cm/540 nm per minute at 30°C and pH 6.9. One amylase inhibiting unit was defined as a decrease of one amylase unit.

The ungerminated and germinated low-tannin varieties inhibited salivary amylase by an average of 7.3 units.

The high-tannin extracts stimulated salivary amylase by an average of 7.1 units. In Udo, the germinated sample produced less stimulation compared to the ungerminated one.

On the other hand, pancreatic amylase was unaffected by ungerminated Lugugu while all the other samples including high-tannin extracts stimulated pancreatic amylase activity.

(ii) Trypsin

Trypsin activity was not inhibited by raw sorghum extracts from the varieties Lugugu, 5DX and Udo, either ungerminated or germinated.

(iii) Chymotrypsin

The effect of sorghum extracts on chymotrypsin activity are presented in Figure 6.

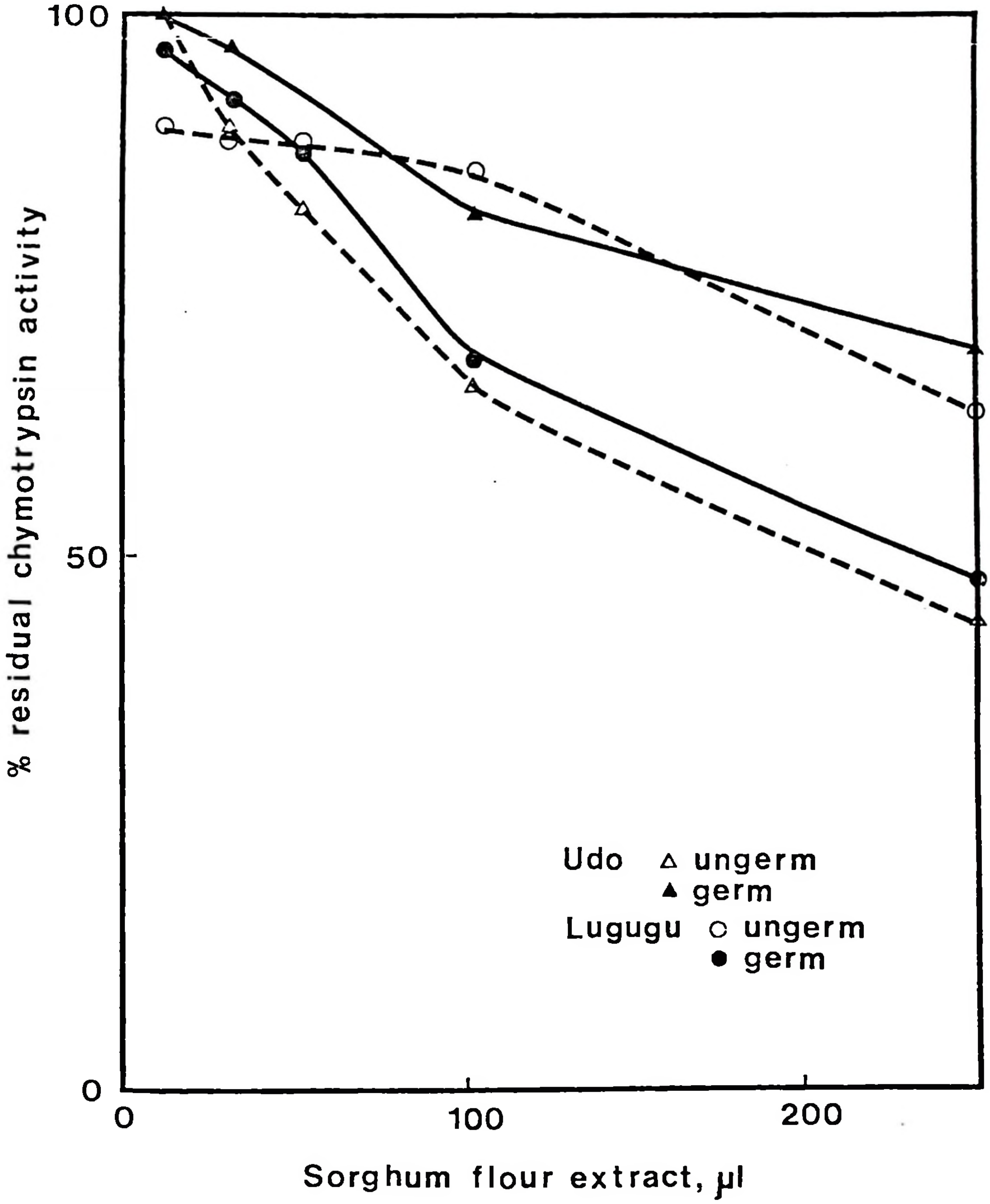

Fig. 6. Residual activity of human chymotrypsin.

Chymotrypsin was not inhibited by the ungerminated or germinated high-tannin variety 5DX. However from Fig. 6, Lugugu and Udo, both inhibited chymotrypsin. Inhibition by Lugugu was increased from 37 % to 52 % after germination, using 250 ul of flour extract. Inhibition by Udo was decreased from 56 % to 32 % after germination.

Looking at both human trypsin and chymotrypsin, no correlation was observed between tannin content and inhibition of the enzyme activity.

5.3.0 Dietary Bulk

This section covers viscosity measurements of gruels prepared in the laboratory and at village and household level. Sensory evaluation related to bulk, namely texture of gruels is presented. Finally, the Luganga village study includes acceptance of bulk reduced cereal gruels and food intake by preschool children.

5.3.1 Gruels Prepared from Ungerminated and Germinated Sorghum Flour

The viscosities of gruels prepared from different germinated and ungerminated flours in increasing amounts (5-25 % counted as dry matter) are presented in Figure 7.

All the ungerminated flours had very similar concentration - viscosity relationships (Fig. 7). Increasing the dry matter in the gruels above 7.5 % would result in a rapid increase in the viscosity of the prepared gruels measured at 40^{o}C. With germinated flours, large differences were observed between the varieties studied. For both the white sorghum varieties

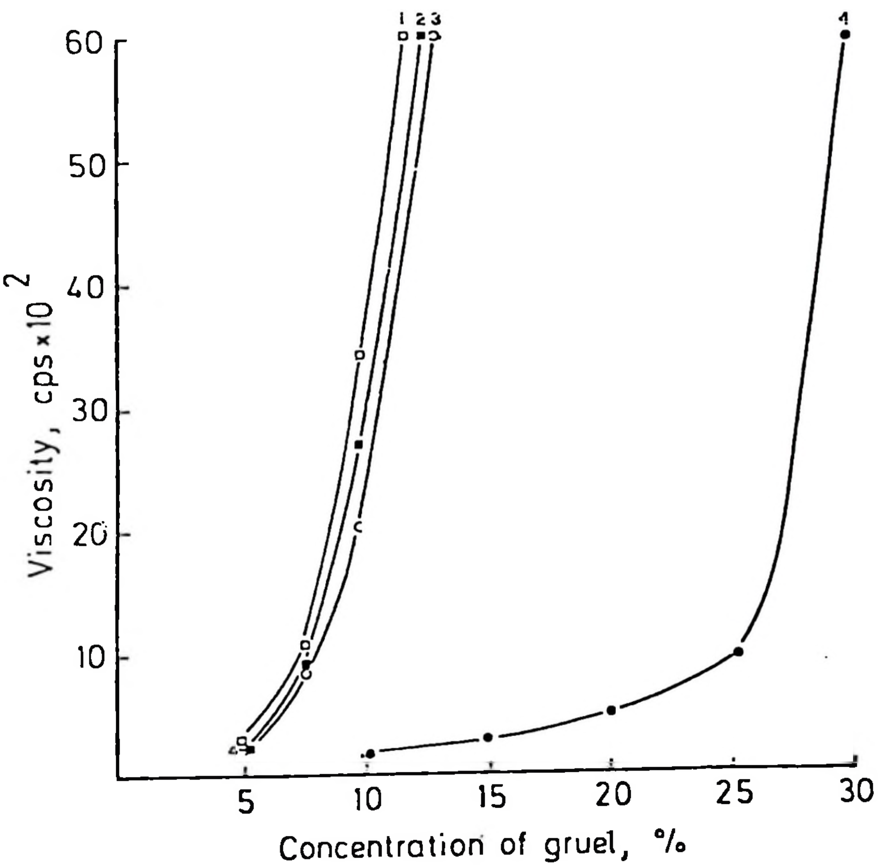

Fig. 7. Viscosity curves of various gruel concentrations of ungerminated and germinated grains. (1) 5 DX, ungerminated, (2) 5 DX, germinated, (3) ET-35, ungerminated, (4) ET-35, germinated.

the amount of flour in the gruels could be increased considerably to about 25 % before the viscosity of the gruel rapidly increased.

The improved brown sorghum variety (5DX), however, showed no effect of germination for 48 hours, on the concentration-viscosity relationship. After extending the germination time to 96 hours, a small reduction in viscosity occurred.

(b) Gruels Prepared from Ungerminated Flour with Germinated Flour Added

It was evident from the results in the previous section that the germinated low-tannin varieties contained active amylolytic enzymes. Germinated (enzyme rich) flour was thus added to gruels prepared from ungerminated flour before and after cooking and the effect on viscosity measured.

(i) Addition after Cooking

Results of adding germinated flour to cooked gruels are presented in Figure 8. In this figure white local sorghum refers to the variety Lugugu, while ET-35 is the white improved sorghum. Local brown refers to the variety Udo, while brown improved refers to the variety 5DX.

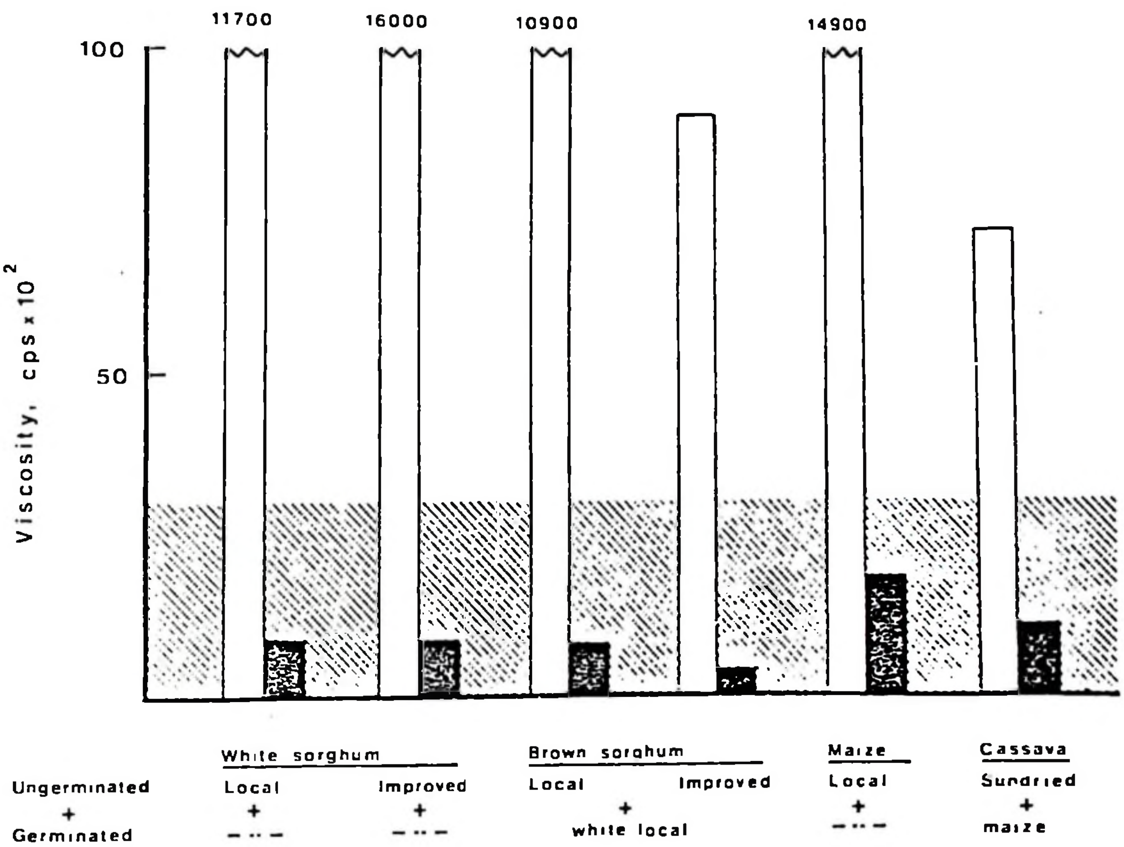

Fig. 8. Viscosity of gruels with ungerminated flour, concentration 15% at 40°C ☐ ; after addition of germinated flour at 40°C and viscosity measured after 10 minutes ▩ . Acceptable eating consistency for children of approximately 1-3 years ▨ .

Fig. 8 shows how the viscosities of thick gruels cooled down to $40^{o}C$ after cooking were affected by added germinated flour. Prior to addition, the gruels prepared from ungerminated sorghum flour (15 % dry matter) had viscosities ranging from 9,000 to 16,000 cps at $40^{o}C$, i.e. thick consistencies. With the addition of a small amount of germinated flour of the white (low-tannin) sorghum varieties, the viscosity decreased within 5 minutes to below 1,000 cps, which was a semi-liquid consistency suitable for child-feeding. Only about 5 % (of the total amount of flour) of germinated flour was required for this effect, and both white (low-tannin) sorghum varieties were equally effective. No effect from the brown (high-tannin) sorghum germinated for 48 hours was obtained.

In order to determine the heat sensitivity of the amylolytic enzymes in the germinated flours, the germinated low-tannin sorghum flour (Lugugu) was added to thick gruels at different temperatures. The results are presented in Figure 9.

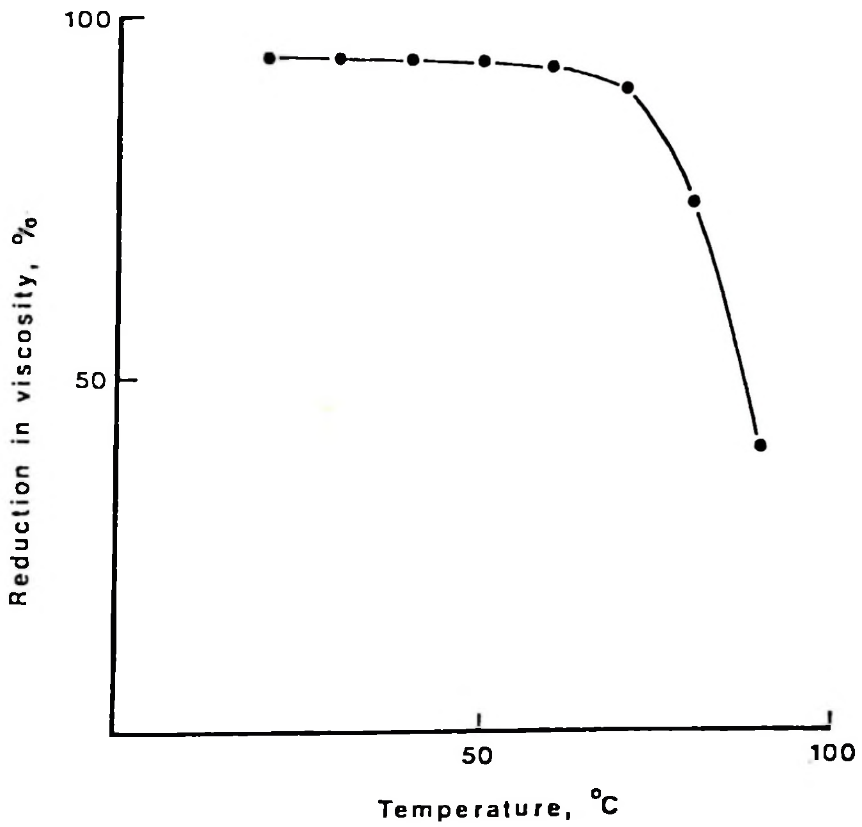

Fig. 9. Reduction of viscosity by addition of germinated flour to gruels of ungerminated flour (15% concentration) at different temperatures.

Figure 9 shows that the germinated flour could be added at any temperature between 20°C and 70°C with the same viscosity-reducing effect. Above 70°C, however, the enzyme activity decreased rapidly with increasing temperature. At 90°C the activity was about 40 % of that below 70°C, measured as viscosity reduction capacity.

Germinated flour of the white sorghum varieties which had been prepared at village level was also tested in this experiment, and gave the same results as the laboratory-germinated flour.

(ii) Addition Before Cooking

The effect of adding a small amount of germinated white sorghum flour mixed with ungerminated flour before preparation of the gruels is presented in Figure 10.

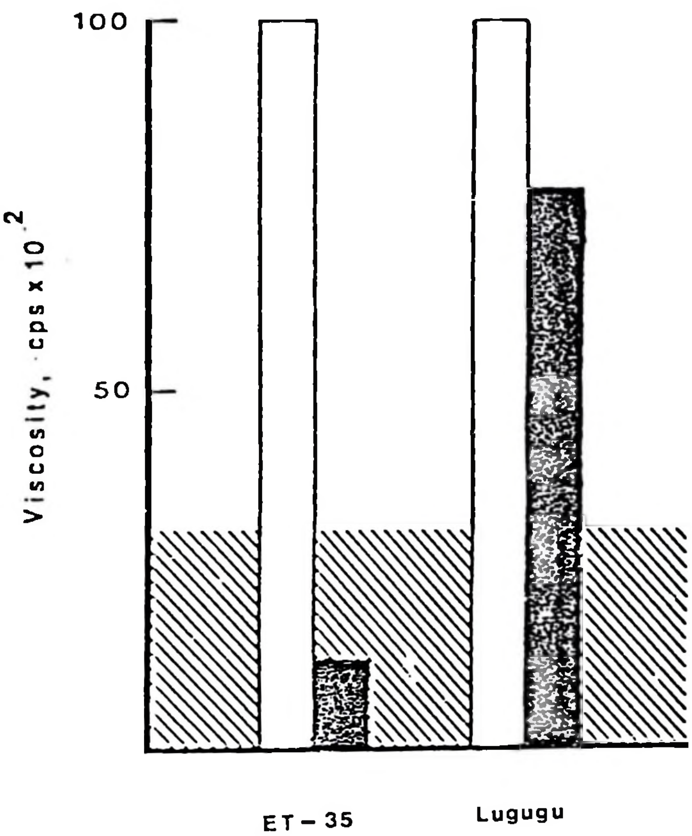

Fig. 10. Viscosity of sorghum gruels with germinated flour added immediately before cooking ☐ and after soaking overnight before cooking ▩. Acceptable eating consistency for children of approximately 1-3 years ▨.

When germinated flour was added to ungerminated flour immediately before cooking the gruel, no viscosity-reducing effect could be observed. In this case, 10 % addition of germinated white sorghum flour was used.

Figure 10 also shows the effect of leaving the mixtures of ungerminated and germinated flours (90:10) to soak in water overnight before cooking. Here the amylolytic activity of the germinated sorghum flour was evidently effective. The gruels prepared from these soaked flour mixtures had markedly reduced viscosities, measured at 40°C. The improved white sorghum variety (ET-35) gave a much more liquid gruel (1,130 cps) than the local sorghum variety (Lugugu) (7,700 cps) after soaking overnight.

5.3.2 Laboratory Sensory Texture Evaluation of Germinated and Ungerminated Sorghum Gruels (Swedish Taste Panel)

Texture terms were defined and scored as follows:

Thickness = viscosity

Like gel = gellified

Grittiness (graininess) = grainy like semolina, porridge; large particles.

Sandiness = the sample felt in the mouth as if it contained fine sand.

The intensities were transferred to scores from 0.0 to 10.0 (0 - low and 10 - high).

The means of the scores are summarised in Figure 11.

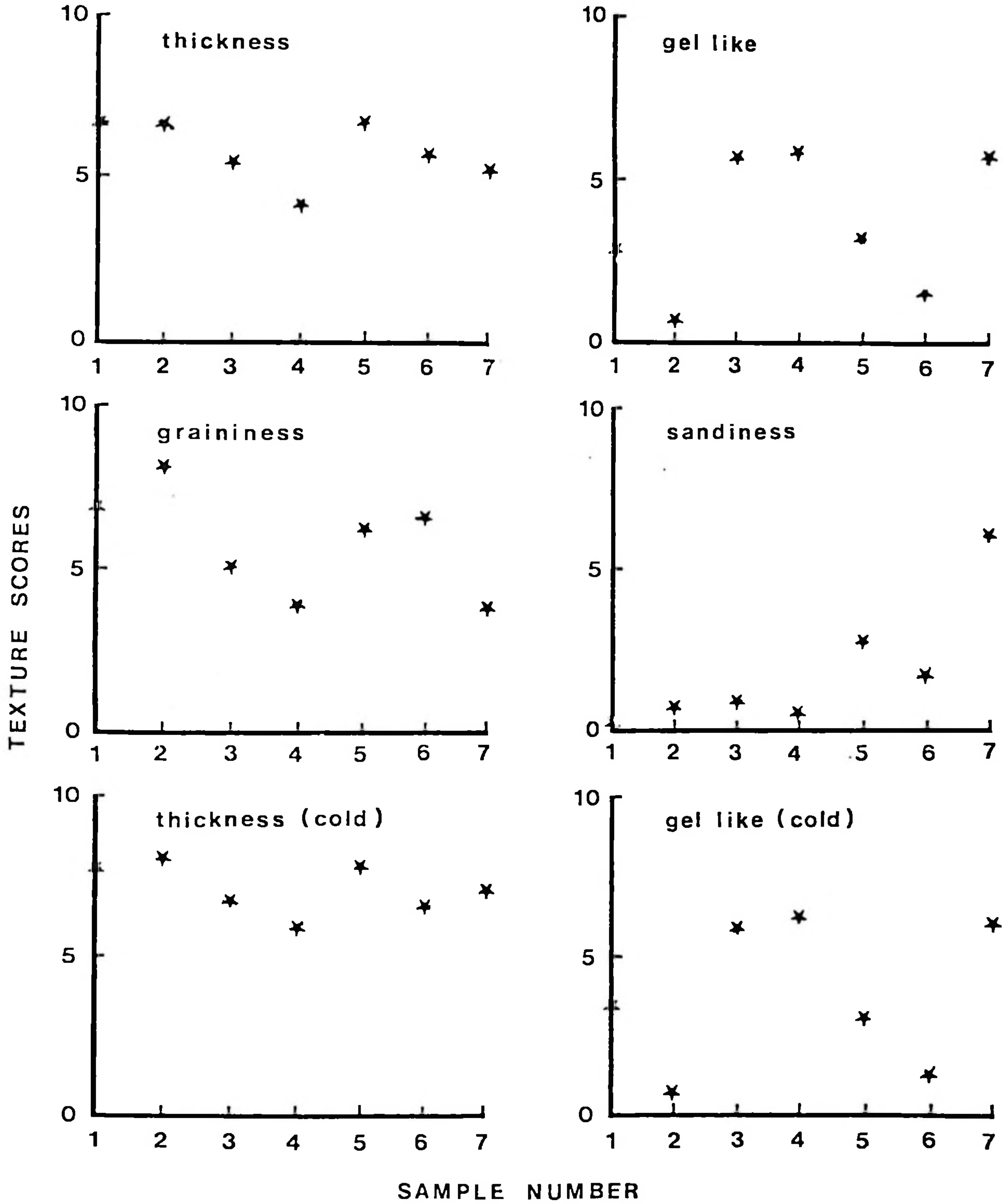

Fig. 11. Taste panel texture evaluation of sorghum gruels. (1) ET-35 ungerminated, (2) ET-35 germinated, (3) 5 DX ungerminated, (4) 5 DX germinated, (5) Lugugu ungerminated, (6) Lugugu germinated, (7) Udo ungerminated. All samples were traditionally dehulled and hammer milled.

Figure 11 shows that the warm samples were all thick, grainy and gel-like. This was of course to be expected. However, there were large differences with, for example 1, 2 and 5 being thickest, 1, 2, 5 and 6 most grainy/gritty and least gel-like; and 3, 4 and 7 most gel-like and least grainy/gritty.

After chilling down to room temperature, the samples became rather much thicker - as expected - but the differences among the samples remained approximately. The curve for "gel-like" looked very similar for warm and cold for corresponding samples.

The high average for "sandiness" for sample 7 (Udo) was due to sand contamination. Also samples 5 and 6 had rather high sandiness averages, although much lower than sample 7 due to the same reason since both samples had been threshed on the ground at village level. There was no doubt among the judges that they meant that the sandiness was different from graininess/grittiness. The low average for sandiness for sample 1 was almost "negligible". The averages around 1 for samples 2-4, were negligible too, since both were all threshed on canvas and handled under clean conditions.

5.3.3 Luganga Village Study

The Luganga village study included observations on the acceptance of bulk-reduced cereal weaning foods, adoption of the "Power Flour" by mothers at home, food intake by preschool children and their growth (weight).

(a) Acceptance of Bulk Reduced Maize Porridge by Mothers at Village Level

Mothers attending the village MCH clinic were used as a consumer taste panel to test the acceptability of a maize/groundnut flour porridge thinned down by the addition of germinated white sorghum flour (Lugugu). The findings are given in Table 38.

Table 38. Acceptance of Bulk Reduced Maize Porridge by Mothers at Village Level

Household	Test Scores[a)]				
Identification	Smell	Colour	Taste	Texture	Readiness to Feed It to Own Children
1	5	4	4	5	4
2	4	5	5	4	4
3	4	4	3	4	5
4	5	4	5	5	5
5	5	5	4	4	4
6	4	4	5	4	5
7	4	4	4	4	3
8	5	4	5	5	4
9	5	4	4	4	5
10	5	5	4	5	4
11	4	5	5	5	4
12	4	5	4	4	5
13	5	5	5	5	4
14	5	5	5	5	3
15	5	5	4	5	5
16	5	5	5	5	5
17	5	5	5	5	4
18	5	5	4	5	5
Mean	4.3	4.6	4.4	4.6	4.3

a) 0 score - low acceptance

5 score - high acceptance

The mothers readily accepted the bulk reduced porridge as evident from Table 38. Smell, colour, taste and texture, all scored above 4.2 out of a maximum of 5 points. This showed that the product was very much accepted as might be expected, since it was not very different from their usual unsupplemented weaning porridge. The score of 4.3 for "readiness to feed the porridge to own children", implied favourable potential adoption of the concept and product at home. To test this, the following investigations were carried out.

(b) Adoption of "Power Flour" by Mothers at Household Level

The objective was to see how 40 mothers accepted "Power Flour" and used it at home for making weaning foods. The findings are presented in Table 39.

Table 39. Adoption of "Power Flour" by Mothers in Households (%)

Response	April	May	July (1983)
Used Power Flour almost every time weaning food was prepared	12.5	17.5	27.5
Used Power Flour only half the time weaning food was prepared	15.0	15.0	22.5
Used Power Flour only a quarter of the time	20.0	25.0	35.0
Used Power Flour several times	35.0	30.0	10.0
Do not remember	17.5	12.5	5.0
Total	100	100	100

The 40 mothers highly adopted the simple method of reducing dietary bulk using germinated sorghum or maize flour over a 3-month period. The group that used the method "every time weaning food was prepared", increased from 12.5 to 27.5 %. Over the same period, considering the women who used the germinated flour "a quarter of the time" and upwards, whenever weaning food was prepared; the percentage doing so increased from 48 % to 86 %. Studies on actual food intake by selected children from households regularly using "Power Flour" were later undertaken.

The weights of the children participating in the intake study were monitored for 10 months.

Typical weaning maize flour porridge preparations made by selected mothers and then bulk-reduced by the use of "Power Flour" are presented in Table 40. The viscosity measurements were done right in the house with the family participating.

Table 40. Effect of Added "Power Flour" on the Viscosity of Gruels Prepared by Mothers at Home (Maize Gruel + 5 % Groundnuts)

Household[1]	Viscosity From Household Gruels[2] (cps x 1000)		Temperature °C	% Solids w/w
	Without Power Flour	With Power Flour		
I	120.0	10.0	38	18
II	240.0	5.0	50	23
III	280.0	7.0	43	25
IV	170.0	4.0	42	18
V	80.0	1.5	38	15

1. Household identification
2. Viscosity for the samples with "power flour" was read at a temperature, about 2°C below the sample without "power flour". A spindle speed of 2 rpm was used for all the determinations.

The viscosity of the gruels had solids content ranging from 15 to 25 %. The viscosity of gruels without "power flour" ranged from 80,000 cps in household (V) to 280,000 cps in household (III). The addition of power flour reduced the viscosity considerably to a range of 1,500 to 10,000 cps.

(c) The Effect of "Power Flour" on Improved Home Level Weaning Foods. Double and Multi-Mixtures

(i) Double Mixtures

Reduction of dietary bulk using either germinated maize or white sorghum flour was achieved. The recipes derived from locally available food items (double mixtures) and bulk reduction by the use of germinated sorghum flour (Lugugu) are presented in Table 41.

Table 41. The Effect of "Power Flour" on Improved Local Weaning Porridges (Double Mixtures)[a)]

Recipe (Flour)	% Solids Un-cooked W/W	Viscosity x 1000 cps[b)] (-) Power Flour	(+) Power Flour	Reduction Factor
Maize and	5	2.2	0.1	22.0
5% groundnut	10	10.0	1.0	10.0
	15	40.0	7.5	5.3
	20	210.0	60.0	3.5
White Sorghum	5	2.5	0.5	5.0
(Mbangala)	10	12.5	1.3	10.0
+ 5% groundnut	15	75.0	2.5	30.0
	20	212.6	7.5	28.3
Brown Sorghum	5	1.5	0.5	3.0
(Serena)	10	17.5	1.0	17.5
+ 5% groundnut	15	175.0	10.0	17.5
	20	275.0	32.0	8.6
Finger Millet	5	2.5	0.3	8.3
+ 5% groundnut	10	12.5	0.5	25.0
	15	100.0	5.0	20.0
	20	140.0	7.5	18.7
Rice	5	0.5	0.1	5.0
+ 5% groundnut	10	52.0	1.5	34.7
	15	86.0	7.5	11.5
	20	457.5	9.5	48.0

a) Germinated sorghum (Lugugu) was used at 5 % as "Power Flour".

b) Brookfield viscometer at 40^{o}C with spindle number 6 at 2 rpm.

Maize porridge at 10 % solids without "power flour" had a viscosity of 10,000 cps and at 20 % the viscosity was 210,000 cps. Addition of "power flour" reduced the viscosity to 1,000 and 60,000 cps, respectively. The average viscosity-reduction factor was 6.

White sorghum (Mbangala variety) porridge had a viscosity of 2,500 cps at 5 % solids, and a viscosity of 212,600 cps at 20 % solids without "power flour". The addition of "power flour" reduced the viscosity to 500 and 28,300 cps, respectively. The viscosity over the range of solids tested was reduced by an average factor of 18.

Brown sorghum (Serena variety) had a viscosity of 1,500 cps at 5 % solids, and a viscosity of 275,000 cps at 20 % solids. Adding "power flour" reduced the viscosity to 500 and 32,000 cps, respectively, giving an average viscosity-reduction factor of 12 over the range of solids content examined.

Finger millet at 5 % solids had a viscosity of 2,500 cps and at 20 % solids the viscosity was 140,000 cps without "power flour". The viscosity was reduced to 300 and 7,500 cps, respectively, by adding "power flour" giving an average viscosity-reduction factor of 18.

Rice had only 500 cps viscosity at 5 % solids but a high viscosity of 457,500 cps at 20 % solids, without "power flour". When "power flour" was added, the viscosity was reduced to 100 cps and 9,500 cps, respectively, giving an average viscosity-reduction factor of 25.

To summarize, the addition of "power flour" reduced the viscosity an average of 6 times in maize porridge, 18 times in white sorghum porridge, 12 times in finger millet porridge and 25 times in rice porridge.

(ii) Multi-Mixture Weaning Foods

The bulk-reduction ability of germinated white sorghum flour, after successfully being tested in double mixtures, was further investigated using improved weaning foods formulated using a mixture of locally available foods.

The recipes were first prepared, tested and found acceptable to the research team (6 people) and a consumer panel of 20 people at the Nutrition Centre (TFNC) in Dar es Salaam. The viscosity and bulk-reduction factors for the different recipes are presented in Table 42.

Table 42. Effect of "Power Flour" on Improved Local Weaning Food Multi-Mixtures Prepared as Gruels[a)]

Recipe (g) W/W		Gruel % Solids	Viscosity cps x 1000 (-) Power Flour	Viscosity cps x 1000 (+) Power Flour	Temperature ^{o}C	Viscosity-Reduction Factor
A. Maize Flour	75					
Pumpkin leaves	10	9.5	25.0	2.1	43	11
Groundnut	15					
B. Maize Flour	70					
Cowpeas	25	11.0	42.5	3.0	43	14
Groundnuts	15					
Sweet potatoes	10					
C. Sorghum (Lugugu)	75					
Kidney beans	25	7.5	10.0	1.0	48	10
Cassava leaves pounded	10					
D. Cassava Root	236					
Cowpeas	45	11.5	15.0	1.0	42	15
Pumpkin leaves	20					
Groundnuts	20					

a) Spindle speed 2 rpm

All four recipes prepared as gruels reduced their viscosities by a factor of 10 to 15 times when germinated flour was added at a temperature of about 40°C.

(d) Food Intake by Preschool Children at Luganga Village

40 preschool children were initially chosen for the study but eventually 8 were excluded because of frequent absence or migration from the village. The results on food intake are presented in Table 45 and Figures 12 to 15.

Overall, there was wide variation in individual food intake within groups (Tables 43 and 44). The small age group (5-12 months) averaged 156 g of porridge per meal, considering all diets.

Group II (12+ to 24 months) had a range of 277 $\pm$ 95 g mean food intake per meal for the 20 % solids porridge without "power flour", to 347 $\pm$ 94 g for the bulk-reduced porridge. There was no significant difference between the 5 % solids porridge and the 20 % solids porridge, with or without "power flour". However, the intake of the 20 % solids porridge with "power flour" was significantly higher than the same porridge without "power flour" ($p<0.05$).

Group III (24 to 48 months) had an average food intake per meal ranging from 405 g for the 20 % bulky porridge to 491 g for the 5 % watery gruel. However, the intake of the 20 % solids porridge with "power flour" was significantly higher than the same porridge without "power flour" ($p<0.05$). Thus significantly hihger food intakes were obtained on gruels with low viscosity, either 5 % solids or 20 % solids but viscosity-reduced with added germinated flour.

Group IV (48 - 65 months old) had less variation in individual food intake and there was no significant difference in food intake between the three diets which averaged 542 g per meal.

For scrutiny, the group food intake of the gruels are presented in Figure 12 for group II and III combined (18 children).

Table 43. Intake of Maize Porridge with Different Bulk Properties by Preschool Children at Luganga Village[a]

Child's Number and Age Group	Maize Porridge (g) Mean Values and Standard Deviation		
	5% Solids (liquid)	20% Solids (thick) without Power Flour	20% Solids (liquid) with Power Flour
I - 5 to 12 months			
1	63	68	58
2	187	143	151
3	123	158	133
4	241	243	310
$\bar{x}$	153	153	162
II - 12+ to 24 months			
5	355	415	383
6	266	314	346
7	271	228	279
8	230	161	287
9	201	213	213
10	352	199	335
11	568	396	522
12	399	292	409
$\bar{x}$	330 ± 118	277 ± 93	347 ± 94
III - 24+ to 48 months			
13	156	226	307
14	466	294	296
15	318	309	288
16	282	333	230
17	626	525	608
18	751	673	746
19	702	528	629
20	455	441	465
21	700	276	399
22	458	444	478
$\bar{x}$	491 ± 201	405 ± 141	445 ± 172
IV - 48+ to 65 months			
23	527	481	727
24	535	487	451
25	548	466	553
26	320	324*	420
27	520	529	604
28	599	646	590
29	630	510	548
30	616	723*	699
31	523	535	484
32	622	472	576
$\bar{x}$	544 ± 90	517 ± 107	565 ± 99

a) Single meal measurements once per month for 6 months. Mean individual values for each diet.

Table 44. Statistical Summary of Food Intake Data for Different Age Groups[1)2)]

Group	5% Solids (liquid)	20% Solids without power flour (thick)	20% Solids with power flour (liquid)
I (n=4)	154 ± 77^{a}	153 ± 72^{a}	163 ± 106^{a}
II (n=8)	330 ± 118^{ab}	277 ± 93^{a}	346 ± 94^{b}
III (n=10)	491 ± 201^{a}	405 ± 141^{b}	445 ± 172^{a}
II+III (n=18)	420 ± 184^{a}	348 ± 135^{b}	401 ± 148^{a}
IV (n=10)	544 ± 90^{a}	517 ± 107^{a}	565 ± 99^{a}

[1)]The Wilcoxon signed rank test for paired samples.

[2)]Mean values within the same group (row) not having a common superscript are significantly different at $p \leq 0.05$.

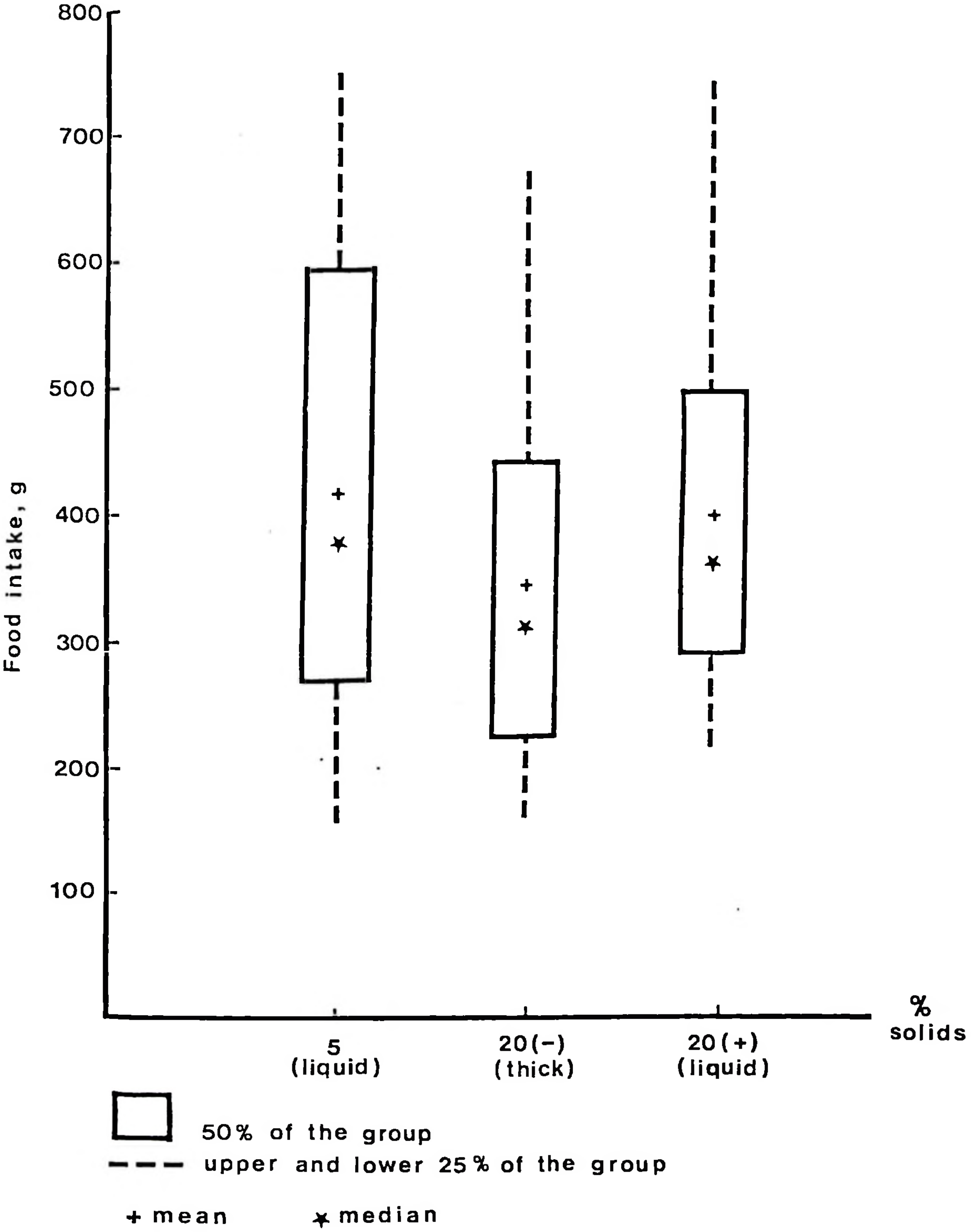

Fig. 12. Food intake by preschool children (12-48 months). n = 18.

Figure 12 shows that 50% of the children, 12 to 48 months old, had food intake lying between 280-600 g for the liquid porridge (5 % solids). The liquid bulk-reduced (20 % solids) porridge had a range of 290-490 g for 50 % of the group. These two diets were low in viscosity but different in nutrient density. The thick bulky porridge gave a range of 220-430 g for 50 % of the group

(e) Monitored Weights of Children

The weights of the children in the study at the beginning and end of the observation are given in Table 45.

Ages at the end of the study ranged from 19 to 52 months. The initial weights ranged from 6.5 to 11.0 kg while the final weights ranged from 7.0 to 13.0 kg. One child lost 1 kg in weight, one recorded no change, and the rest gained from 1 kg to 3 kg over the period.

Table 45. Weight Changes for Children[a] Regularly Using "Power Flour" Treated Porridge for 10 Months (n = 12).

Initial Age (months	Weight (kg)	% of standard[b]	Weight gain per month (g)
10	7.5	81	200
12	6.5	66	150
16	7.0	64	0
18	9.0	80	100
20	8.0	68	100
20	9.0	77	150
24	10.0	81	50
24	10.0	81	100
24	9.0	73	-[c]
30	8.5	63	150
42	11.0	71	200
42	10.0	65	300

a) Single children randomly chosen from households not included in the food intake study. Age and weight at the start of the study.

b) Standard weight for age, Harvard standards (TFNC, 1977).

c) Lost 1 kg over the period.

CHAPTER VI

6. DISCUSSION

In the previous chapter the results were presented according to the treatment of the samples mainly milling and germination. A similar pattern was followed in this chapter with emphasis on germination effects on nutrient content, nutritive value and dietary bulk. Particular attention was paid to: relating our findings to previous work, pointing out similarities or differences: critical evaluation of others' findings compared to ours: explanation where relevant, significance of the results and their practical application. Topics which were not adequately dealt with needing more research were pointed out and finally arguments for or against our original hypotheses were considered.

6.1.0 Chemical Composition

The chemical composition investigated covered proximate analysis, amino acids, fibre, minerals and antinutritional factors. In general our findings were similar in many ways to previous results on sorghum (Wall and Blessin 1969, Doggett 1970, Neucere and Sumwell 1980, Hulse *et al*. 1980a) and other cereals (McCance and Widdowson 1969).

Details are given in the following sections.

6.1.1 Proximate Composition

The moisture content of above 12% in some of the sorghum grain, as harvested, was above the critical moisture level for mould and fungal growth (Castor and Fredriksen 1982) and might cause aflatoxin health hazards (Seenapa and Nyagahungu 1982, Temalilwa 1983 and Kavishe 1983), lower grain quality, and hence the need for farmers to thoroughly dry the grain before storage to avoid losses (Mushi *et al*. 1983).

The energy content of the flour was in the expected range (396-425 kcal/100 g) for cereals since the bomb calorimeter method included all combustible grain constituents (McCance and Widdowson 1969).

The crude protein (9.6-11.8%) content of the samples (Table 20), were close to reported values for normal sorghum from Tanzania (Muindi and Thomke 1981, Eggum et al. 1982), Ethiopia (Ågren and Gibson 1968), and East Asia (Leung, Butrum and Chang 1972).

The crude protein content as expected was however less than in high lysine varieties (Singh and Axtell 1973), whose values were about 50-60% higher than normal sorghum varieties. The finding that germination did not affect total crude protein content was expected considering the short time (48 hours) of germination used in this study.

Dehulling by the traditional method or abrasion, reduced the crude protein content. This was mainly due to the removal of part of the aleurone layer which is rich in protein content and agreed with previous similar observations on sorghum milling by Rangavendra Rao and Desikachar (1964), Eggum et al. (1982) and Pedersen and Eggum (1983).

The content of fat in the whole grain was reduced by germination and resembled results on maize (Ågren and Gibson 1968). The lower values obtained for the traditionally and abrasively dehulled grain arose mainly from the loss of the germ which is rich in oil.

The ash content in the local varieties were higher than previously reported values but this could be explained through contamination by sand and soil. Similar observations have also been reported on Ethiopian sorghum from rural areas (Almgard 1963). Reduction of ash content by dehulling and germination were mainly due to the removal of the ash-rich bran and contamination by decortication and washing during the germination procedure respectively.

6.1.2 Amino Acids

Generally the amino acid pattern for the whole flour from the four sorghum varieties (Table 19) was in agreement with other results on normal sorghum (Narayana Rao and Polacchi 1972, Ågren et al 1975), East African varieties (Shepherd et al. 1971-72), some Tanzanian varieties (Eggum et al. 1982), and Nigerian varieties (Ajakaiye 1984). Our findings confirmed that lysine was the first limiting amino acid as indicated by the chemical scores. This was in agreement with other workers (Axtell et al. 1982, Jambunathan et al. 1983) and earlier work by Nawar et al. (1970), Bakshy et al. (1978), and Harden et al. (1976). The lysine values were however lower than in wheat, maize, rice and barley as reported by Eggum (1973), and in millets (Virupaksha et al. 1975 and Monteiro et al. 1982).

The increase of lysine content in all the varieties by germination was in agreement with similar observations on sorghum by other workers such as Wu and Wall (1980) who worked on normal and high-lysine sorghums, normal maize (Tsai et al. 1975), wheat (Chitenden et al. 1978), barley, rice, oats and rye (Dalby et al. 1976). The aforementioned studies also reported increments in the essential amino acids due to germination of the cereals and was also confirmed by the results of Taylor (1983) on malted sorghum.

The reduction of amino acid content by milling (Tables 20 and 21) was similar to other studies on sorghum as reported by Shepherd et al. (1971-72), Eggum et al. (1982) and Pedersen and Eggum (1983).

6.1.3 Fatty Acids

The pattern of the fatty acids in the four varieties (Table 24) was in good agreement with previous findings on American sorghum varieties studied by Rooney (1978) and Neucere and Sumwell (1980). The essential fatty acids: oleic, linoleic and linoleic acids which are unsaturated, could be of major public health importance where sorghum provides much of the dietary oil. The fatty acid content patterns for the varieties resembled that of maize but differed from pearl millet which has more saturated fatty acids (palmitic and stearic) as reported by Rooney (1978).

6.1.4 Dietary Fibre, Neutral Sugars and Uronic Acids

The total dietary fibre content (Table 23) was within expected values (9-20%) for sorghum compared to similar work on low-and high-tannin sorghum varieties from the Sudan using similar methods (Bach-Knudsen and Munck 1984, Nyman et al. 1984).

The traditional dehulling method decreasing corrected dietary fibre by about 40% for the low-tannin samples and 20% in the high-tannin samples demonstrated the utility of traditional dehulling but it also led to high nutrient losses as already described.

The values on dietary fibre content were much higher than crude fibre content determined by acid and alkaline digestion for whole sorghum reported in the literature (3-5% by Ågren et al. 1968). However, the combined enzymatic and gravimetric method used in the present study (Asp et al. 1983) simulated human digestive tract conditions. Therefore the dietary fibre fraction included the non-starch polysaccharides plus lignin and also such components as tannin-protein complexes and modified starch. Since food fibre binds important nutrients such as minerals in vitro (Fernandez and Phillips 1982, Eastwood and Passmore 1983), the findings could contribute to the understanding of nutrient availabiltiy in vivo.

Dietary fibre, being undigestible to a high extent, is also filling in the gut, absorbs and binds much water and limits the amount of total solids which could be ingested especially by young children and may therefore contribute indirectly to the dietary bulk problem (Kelsay 1978, Kearns and Lowy 1980, Eastwood and Passmore 1983).

The relative percentage content of glucose, arabinose, xylose, galactose and uronic acids, were in accordance with findings by Nyman et al. (1984).

6.1.5 Mineral Content

The mineral content in the samples were all in the expected range as reported in Food Composition tables referred to later, except zinc (Table 25), since the samples were analysed as harvested.

Calcium content was in agreement with published values for sorghum (Ågren et al. 1968 and Platt 1962). Reduction of calcium by dehulling was due to the removal of the bran, while washing during the germination procedure would have removed contamination minerals.

The phosphorus content in the samples and reduction in value during dehulling and germination could be explained as was the case in calcium.

The iron content as already stated under ash was higher than literature values in the varieties Lugugu and Udo. Sand and soil contamination explained the high values since the samples were collected from a ferrallitic soil type area, threshed on the ground and milled into flour in a hammer mill made of iron. This observation resembled previous reports on Indian sorghum purchased from local markets (Prabhavathi and Narasinga Rao 1981).

Zinc values in the ungerminated samples were within reported values for sorghum (Deosthale et al. 1977, Statens Livsmedelsverk 1978). However, the germinated samples had higher values than the ungerminated values possibly due to contamination from the water used during the germination procedure.

6.1.6 Vitamins

The vitamin content (Table 26) in the samples were within the range of reported values for ungerminated whole grain (Miller 1958, Ågren and Gibson 1968 and Leung, Butrum and Chang 1972, Brandtzaeg et al. 1981). The highly significant increments in vitamin content during germination in thiamine, riboflavin and niacin confirmed the results of Brandtzaeg et al. (1981) on Indian sorghum samples and work on malted millets by Aliya and Geervani (1981) and germinated legumes (Fordham et al. 1975).

6.1.7 Tannins

The range of tannin content (Table 27) of 3.06 to 5.90% as catechin equivalents, were in close agreement with findings by other workers using many different high-tannin sorghum varieties and a similar analytical method, as aptly summed up by Butler (1982) who reviewed a very wide range of sorghum types as well as Radhakrishnan and Sivaprasad (1980) and Earp et al. (1981). Muindi and Thomke (1981) using a different method obtained lower tannin values for other Tanzanian sorghum varieties.

The analytical method used (Price and Butler 1978a) was chosen as it had been critically evaluated in comparison with other methods by the authors and was found to be specifically suitable for sorghum tannins.. During the analysis, care was taken to use dry samples since water lowers measurable tannins by enhancing tannin/protein binding (Reichert et al. 1980).

Different treatments of the high-tannin varieties had varying effects. Brief mild acid washing of the grains reduced the tannin content possibly due to polymerization or leaching and was in agreement with previous work using 0.9 molar HCL (Reichert 1980). Soaking in distilled water for 24 hours reduced seed tannin content possibly through leaching since the soaking water turned a deep brown colour. The reduction in assayable tannin agreed with reported results (Price and Butler 1980a).

The decrease in assayable tannin in the brown varieties during germination could have been due to polymerization and complex formation with proteins as reported in related sorghum work by McGarth et al. (1982)

and Glennie (1983). Reduction of measurable sorghum tannin by mild alkaline soda solution agreed with previous findings (Price and Butler 1978b, Price et al. 1979b, Muindi et al. 1981). Dehulling and reduction of tannin content by traditional and abrasive methods, agreed with other sorghum results (Chibber et al. 1978, Pedersen and Eggum 1983). The significance of our observations on the nutritive value of sorghum are dealt with later.

6.1.8 Phytin-Phosphorus

The level of phytin-P (Table 28) in the ungerminated whole flour for the four varieties was 89% of the total phosphorus and this was within the range reported in sorghum by Wang et al. (1959) and Pedersen and Eggum (1983).

Lowering of the phytin-P by germination could be explained by hydrolysis of the phytate by the enzyme phytase which is present in sorghum (Adams et al. 1976) and might have increased during germination and released phytin-phosphorus.

6.2.0 Sorghum Nutrients Availability

6.2.1 In Vitro Nutrient Availability

(a) Protein Digestibility

The nutritional value of dietary proteins depends on the protein quality which is a function of the amino acid pattern and the digestibility of the protein. The in vitro protein digestibility method of Axtell et al. (1981), gave results which approached the few human studies reported on sorghum protein digestibility in young children (MacLean et al. 1981, 1983) indicating that in vitro protein digestibility could be used to predict digestibility in humans. This assumption is supported by earlier research by Bodwell et al. (1980) who, using proteins of animal and vegetable origin, found good correlations between human, rat and in vitro digestibility methods.

Our findings therefore are indicative of sorghum protein digestibility (Table 29) whereby the whole raw, ungerminated low-tannin sorghum varieties had high protein digestibilities, averaging 85% and the high-tannin varieties averaging 58%, which supported similar findings on different sorghum varieties using the same method (Axtell et al. 1981).

The cooked, dehulled low-tannin ungerminated samples in this study averaged a low protein digestibility of 46% which is comparable to the value of 39% reported by Axtell et al. (1981). However, using an improved version of the method (Mertz et al. 1984), they reported 59% pepsin digestibility on normal sorghum though it is not clear whether it was a high- or low-tannin variety. Also Chibber et al. (1980) reported that dehulling high-tannin sorghum improved in vitro digestibility.

The rise in protein digestibility to 100% after germination in the low-tannin varieties and to 69% in one of the high-tannin varieties, stand on their own as there was no similar work reported in the literature. However, it could partly be explained by tannin reduction by the water extraction and/or biochemical and physiological changes, occurring during germination, due to enzyme activity as reported in other sorghum varieties (Aisien and Palmer 1983, Aisien et al. 1983, Wu and Wall 1980, Garg et al. 1970). Germination did not affect in vitro protein digestibility in the high-tannin variety Udo and this could partly be due to seed enzyme inhibition by the tannins as reported in other high tannin varieties (Kumar et al 1978, Kumar et al. 1979, Chukwura and Muller 1982). More research is evidently required to determine the effect of tannins on protein digestibility and the use of in vitro methods to predict human protein digestibility.

(b) In Vitro Iron Availability in Sorghum

There are few methods available for accurate determination of in vitro iron availability, but the method of Narasingo Rao and Prabhavathi

(1978) was chosen as the authors used conditions approaching those in the human digestive tract and has been used on sorghum. The method is rapid, reproducible and not complicated. However, a method proposed later by Lock and Bender (1980) used human pepsin gastric juice from human volunteers instead of bovine pepsin.

Our findings in vitro (Table 32) gave a range of sorghum iron availability from 11 to 56% which was within that of Narasinga Rao and Prabhavathi (1978), whose value was 18% Fe availability but higher than the findings of Prabhavathi and Narasinga Rao (1981) with a value of 3.6% on acid washed local sorghum. Our findings were additionally close to results on other vegetable foods reported by Jacobs and Greenman (1969).

The effect of germination on iron availability was variable, decreasing in Lugugu (low-tannin) and increasing in 5DX (high-tannin) in all the sample except one, the high-tannin variety 5DX. The rise in ionizable iron due to germination in this variety resembled similar high findings on malted ragi (88%) and pearl millet (76%) by Sankara and Deosthale (1983) who used the same method.

6.2.2 In Vivo Nutrient Availability in Sorghum

(a) In Vivo Protein Digestibility in Rats

The low food intake by the rats during the nitrogen balance study was similar to previously reported sorghum studies (Jambunathan and Mertz 1973, Harden et al. 1976, Eggum et al. 1982). Like in our findings, the rats in the quoted studies gained little weight or lost weight during the experiments.

The true digestibility value of the ungerminated low tannin traditionally dehulled varieties (92% TD) was as high as other white sorghum varieties and confirmed similar studies (Eggum et al. 1982, Eggum et al. 1983) whose values on Tanzanian and Sudanese varieties were all over 90%.

Our findings were close to other cereals such as pearl millet 95% (Adrian et al. 1976), maize 83-85% (Ekpenyong 1979), rice 90-95% (Ford and Hewitt 1979), wheat 80-90% (Eggum 1973), and barley 82-92% (Bansal et al. 1977). The low values for the ungerminated whole flour of high-tannin varieties (13-45% TD) were very much lower than that reported by Eggum et al. (1983): their value on high-tannin sorghum porridge (ugali) was above 80%).

The high-tannin variety Udo though, had a significantly higher digestibility after germination, which might be explained by the decrease in measurable amount of tannins. The tannins were either extracted during the soaking procedure or metabolised (Butler 1982), rather than only being bound to the prolamine fraction in the seed. If that was the case, a similarly low digestibility could be expected as in the ungerminated seeds, but this was not the case.

The formation of insoluble starches which lowers sorghum digestible energy has recently been reported by Bach Knudsen and Munck (1984). They suggested that large amounts of sorghum proteins are associated with dietary fibre fractions as observed in our findings (Table 23).

Dehulling removed much of the tannin in 5DX and Udo (Table 21) so by similar argument, the significant improvement in sorghum protein digestibility was expected (Eggum et al. 1982, Pedersen and Eggum 1983).

(b) In Vivo Sorghum Iron Availability in Weanling Rats

The values on iron availability, varying from 34 to 88% of total seed iron were very much higher than the scanty literature values using similar methods, on different sorghum varieties since Fe availability would certainly be variety dependent and also highly dependent on type of iron contamination.

Ifon (1981), feeding rats Nigerian sorghum and pulse diets, reported that 29% of ingested iron was used for haemoglobin synthesis. Earlier Ifon and Bassir (1978), using rats (Fe-depleted), reported values ranging from 7 to 36% in a variety of vegetables. Amin et al. (1982) and Park et al. (1983), using Fe-inorganic salts, laboratory diets and $FeSO_4$ as a standard, found values ranging from 60 to 84% in the efficiency to convert dietary Fe into haemoglobin. Our findings were close to these values. However, in vivo iron absorption by humans from sorghum gruel as reported in the literature was very low at 0.6% (Derman et al. 1980) as our own unpublished results on dehulled low-tannin variety (Lugugu) with 3.8% in a diet containing meat. These observatios underscore the inadequacy of using the rat as a model to predict iron availability to humans, though rat bioassays could be used to compare different diets and their relative contribution to iron availability to humans. Both high-tannin varieties had low iron availability, though the values were higher in germinated 5DX (Table 34). This could be explained by the tannin iron binding effect as reported in high-tannin sorghum varieties by Radhakrishnan and Sivaprasad (1980) and Gillooly et al. (1983). However, the tannin decrease in Udo caused no change in iron availability. There was no change in tannin in 5DX yet iron availability increased. It therefore appears, that iron availability is variety dependent and there was no correlation between iron availability to rats and sorghum tannin content. The same argument would apply to phytin-phosphorus which changed only marginally due to germination.

(c) In Vivo Zinc Availability from Freeze Dried Sorghum Gruels Using Weanling Rats

The values of zinc availability from the cooked sorghum diets varied from 33 to 59% and stand on their own as no similar work was found in the literature using the same method. However, O›Dell et al. (1972), using rat growth responses, reported zinc availability values of 57% for corn, 23% for rice and 21% for wheat. The corn value seems to be close to our findings.

Tannin content and germination had no effect on zinc availability in the sorghum varieties in this study (Table 36).

6.2.3 Inhibitor Effect on Human Digestive Enzymes by Raw Sorghum

Raw low-tannin sorghum extracts, germinated and ungerminated as indicated in Table 37 inhibited salivary and pancreatic amylase close to findings on rye and oats by Granum (1979).

On the other hand stimulation of both salivary and pancreatic amylase by the high-tannin varieties and the germinated low-tannin type (Lugugu), were unique and unexpected. It would appear that the observed effect was characteristic of these varieties.

The presence of protease inhibitors in sorghum, with high activity partly due to tannins in sorghum has been reported before (Filho 1974 and Kumar et al. 1978). The inhibition of chymotrypsin by Lugugu (low-tannin) and Udo (high-tannin) sorghum varieties partly confirmed the results of these workers. The inhibition would appear to be variety dependent as 5DX (high-tannin) had no inhibitory effect.

Reduction of the inhibitory activity by germination could be partly attributed to the lower amount of assayable tannin after germination (Lichtenwalner et al. 1979), Reichert 1980 and Butler 1982).

Human trypsin inhibition was not found in any of the sorghum varieties studied unlike the results of Filho (1974) and Kumar et al. (1978) who had positive results.

6.3.0 Dietary Bulk

6.3.1 Viscosity Measurements

The viscosity measurments as summarized in Figure 7, 8, 9 and 10, were very close to previous related work (Desikachar 1980), Brandtzaeg et al. 1981, Hellström et al. 1981, Karlsson and Svanberg 1982).

Viscosity measurements on gruels of germinated flour showed large differences between the varieties studied. The amount of flour in the gruels of the germinated white sorghum variety could be increased considerably (2-3 times) before the viscosity became unacceptably high. This was evidently a result of starch degradation caused by the action of the alpha- and beta-amylases that developed during the germination procedure (Lineback and Ponpipom 1977, Sheorain and Wagle 1973, Okon and Uwaifo 1984, Mundy 1982).

The amylolytic activity obviously developed more slowly in the high-tannin sorghum varieties. The explanation for this could be the inhibitory effect exerted by the tannins on the activity of amylolytic enzymes in the seed (Tamir and Alumot 1969, Milic et al. 1972, Chukwura and Muller 1982).

As evident from the results on gruels prepared from ungerminated flour with germinated flour added: germinated white sorghum varieties contained active amylolytic enzymes. These enzymes are readily used to degrade the starch in flour that has not been germinated and less water is therefore needed in the preparation. Furthermore, germinated flour needs to be prepared less often which considerably decreases the amount of work that is needed for preparing weaning foods with low dietary bulk, if only germinated flour was used. If the wholesomeness of the added germinated flour were questionable, as might be the case at village level where hygienic conditions could be poor, it would be advisable to reheat the gruel to boiling after allowing time for the enzyme activity. This action did not affect the final viscosity of the gruel. Alternatively, the germinated grain could be lightly toasted and ground hygienically. This would improve the flavour without reducing the enzyme activity much (Brandtzaeg et al. 1981). Considering the practical implications of the results, Table 46 illustrates the significance of the findings.

Table 46. Estimated Consumed Volume of White Local Sorghum Gruels Needed to Cover 60% of Daily Energy Needs for a 1-year-old Child.

	Ungerminated flour	Germinated flour	Germinated flour added to ungerm.[a]
g flour[a]/100 g gruel	8	25	17
Viscosity of gruels (cps)	1,000	1,000	1,000
Volume to cover 60% of daily energy needs[b] (ml)	2,500	800	1,200

[a]Energy content of sorghum flour, 350 kcal/100 g
[b]Energy requirments for a 1-year-old child, 1,180 kcal/day (FAO/WHO 1973)
[c]5% of total dry matter

The amount of white sorghum gruel needed to cover 60% of the daily energy requirements of a 1-year-old child (FAO/WHO 1973) was calculated for gruels with a viscosity of 1,000 cps (a liquid gruel). If ungerminated flour was used, 2,500 ml of prepared gruel had to be consumed by a child. If 5% germinated flour were added after cooking, the amount needed would be 1,200 ml of gruel, and if only germinated flour were used, 800 ml will be enough. It was also shown (Table 40) that gruels up to 25% concentration ungerminated flour can be thinned down to less than a viscosity of 7,000 cps by adding 5% germinated cereal flour. This means that about 800 ml of a bulk-reduced ungerminated flour gruel would also suffice to provide 60% of the daily energy requirments of a 1-year-old child. The dietary bulk of the gruels could be further improved if energy-rich components like cooking oil and groundnuts were added (Dearden et al. 1980). The protein, vitamin and mineral requirements should obviously be considered.

The practicability of bulk reduction was demonstrated by the Luganga village study on viscosity measurements on home-made weaning foods (Table 40). The Brookfield viscosity values on maize porridge with 5% groundnuts, without power flour and containing 15-25% solids ranged from 80,000 cps to 280,000 cps and were higher than the RotoVisco viscometer laboratory values on sorghum porridge. The reduction factors on bulk after adding 5% power flour ranged from 12 to 53. These values were within the expected range and resembled the laboratory findings on sorghum porridge. There was a wide variation in concentration between the different household porridges but all could easily be thinned down by the mothers using germinated white sorghum flour.

The household and laboratory bulk-reduction findings were further confirmed by successful application of the technique to improve home-made weaning gruels based on cereals (sorghum, maize, millet and rice flour), cassava, sweet potatoes and supplemented with groundnuts, legumes or pounded vegetables (Tables 41 and 42).

The observed differences between individual cereals, and root preparations could be due to the different nature and composition of the food components especially the starch content (Ott and Hester 1965, Hellström 1981 and Ljungqvist 1981). The degree of heating and length of cooking also could affect the final solids content and viscosity as reported by Ranghavendra Rao et al. (1983). Different sorghum varieties give gruels which differ in texture and viscosity (Subramanian et al. 1983b).

6.3.2 Sensory Evalutation of Germinated and Ungerminated Sorghum

The texture rating of the gruels (Fig. 9) generally indicated that the low-tannin varieties (ET-35 and Lugugu) which had a flinty endosperm, scored higher than the high-tannin types which had a floury endosperm. Similar observations were reported by Murty et al. (1980) and Mukuru et al. (1982), testing different sorghum porridges (Ugali). The gel scores were, however, lower in the flinty low-tannin varieties than the floury ones, but cold samples had higher scores in all samples implying higher viscosity values.

The sandiness scores were high in Udo and Lugugu due to sand and soil contamination as already explained under ash and mineral contents..

Germination lowered the gel-like scores in the low-tannin varieties thus implying lower viscosity. The high-tannin varieties had significantly higher scores for gelliness.

These findings are significant to sorghum breeders who should consider textural properties of cultivars for they are important in determining sorghum food quality and consumer acceptance (Subramanian et al. 1980b, Pushpamma and Vogel 1982, Morris 1982).

Acceptance of the bulk reduced gruel by the consumer panel of mothers (Table 38) was high. The panel size was small and could have been influenced by the novelty of the concept of thinning thick porridges by adding more "solid" material. The interviewers could have influenced some of the results as mothers might have been polite to please the interviewers. However, the findings confirmed that the bulk-reduced porridge was acceptable to the mothers. This observation was enhanced by the adoption of power flour while making weaning gruels at home. Within three months of promoting the concept, the number of women using power flour most of the time they made weaning food, more than doubled. However, the response could have been prejudiced by inadequate record keeping by the mothers and the inadequacy of the recall method used.

6.3.3 Food Intake by Preschool Children at Luganga Village

The food intake in group I (5 to 12 months old) averaging 156 g/meal was within reported values for infants fed milk formulae with solid foods (Fomon et al. 1969, 1971 and 1975).

Group II (12 to 24 months old), which is the most crucial period during weaning, averaged 318 g of gruel per meal over the period for all diets which was within reported values by Rutishauser and Frood (1973) on Ugandan children fed bulky diets based on local cereals, bananas and cassava. The values were also within the range reported for Gambian children by Black et al. (1983) and Ethiopian children (Svanberg et al. 1984a).

Food intake in groups III and IV (24 to 65 months old) was within reported values for this age group by Ljungqvist et al. (1981) on Ethiopian children, Susheela and Narasinga Rao (1983) on Indian children and Bins (1975) on young children from Papua New Guinea.

There are few reported studies comparing food intake of bulky and bulk-reduced weaning gruels. In this study the bulk-reduced gruel of 20% solids was consumed in equal amounts to the 5% gruel with liquid consistency by all children. However, the thick porridge of 20% solids was consumed significantly less by the children between 12 to 36 months of age.

It therefore seems as the limiting factor was viscosity and not the energy density of the gruels. This was in agreement with the results of Svanberg et al. (1984a) on Ethiopian children fed the sorghum weaning food Faffa , bulk-reduced by the addition of 5% germinated sorghum flour.

Note that the food intake results were based on a single meal a day, once a month for each test sample over a period of ten months. Several factors could have affected the validity of the results thus rendering them indicative rather than exact. The amount of food consumed depended on what the child had already eaten in the morning especially breast milk, though the mothers were requested not to do so. It is not easy to strictly control small children. The appetite of the child and general state of health affect food intake (Rutishauser 1974, Susheela and Narasinga Rao 1983). The attitude of the mother and the influence of other children also affect food intake by young children as reported in some Tanzanian communities in Kilimanjaro (Lema 1963) and Kagera (Rwegelera 1963). More recent studies in Tanzania have confirmed the above as reported in village nutrition surveys (Jonsson and Mgaza 1977, Kimati 1977, Bantje 1983) and general studies by Mgoma (1979) and Omari (1979).

6.3.4 Weight Development of Children Regularly Using "Power Flour" Treated Porridge

All children (n = 12) were below standard weight for age, 63 to 81% of international standards adapted for Tanzania (TFNC, 1977), and were similar to previous observations on children in Developing countries (King et al. 1972). Half of the children were gaining weight at the expected standard rate of 150 g per month or above during the test period. One child showed no weight change and one child lost weight over the test period. For the whole group the average percentage of standard weight remained unchanged during the 10 months. Inspection of weight for age data from MCH records at the village dispensary (Table 17) shows a steady decline in percentage of standard weight between the age-groups of 12 to 24 months. Compared to these data, the children regularly using the "power flour" treated porridges were better off in weight development. However, the weight gain rate cannot be fully attributed to the use of "power flour" in preparing weaning foods for the children since they must have eaten other foods as well and several other health factors were involved, yet the findings suggest a positive effect on weight gain after the use of "power flour" treated weaning foods.

CHAPTER VII

7. NUTRITIONAL SIGNIFICANCE, CONCLUSIONS AND RECOMMENDATIONS

7.0 Recapitulation

In retrospect, the study focused on the nutritional evaluation of sorghum as affected by germination including relevant processing technology for the production of edible sorghum flour and products. The main aspects covered included protein nutritional value, antinutritional factors especially tannins, iron and zinc availability, vitamins: viscosity measurements, sensory evaluation: village level acceptance of bulk reducing methodology and preschool children food intake. The main hypothesis was that germination would reduce bulk, improve nutrient availability and be acceptable at village level for preparing weaning foods in an effort to contribute towards solving the child malnutrition problem. Let us now see how the study met the objectives and our initial hypothesis.

7.1 Nutritional Implications

This section covers significance of the main findings on the use and nutritional value of sorghum: only passing reference is made on the role of sorghum in the existing food situation in Tanzania.

The importance of sorghum is highlighted by the recent drought in Tanzania with wide food shortages especially in regions suitable for sorghum. The government paper (DAily News of June 23, 1984) put it aptly: "Food Supply to Get Priority ... The Gorvernment will give the highest priority to food self-sufficiency in 1984/85 to eliminate the present persistent food shortages, the Prime Minister Ndugu Salim Ahmed Salimu said in the National Assembly in Dar es Salaam yeasterday. ... The recent drought which had hit eight regions had forced the government to spend on food purchases, money which would have been used for development programmes."

As indicated in the background chapter, sorghum, the second most important cereal, like most other food crops, is largely produced by peasant small land holders in Tanzania. Higher production by these farmers may contribute to improve the current bad food situation and minimize dependence on counter-productive agribusiness type of ventures and food aid (Hines and Dinham 1984). Sorghum is used for the monotonous diet of soft or stiff porridge and beer making in Tanzania, implying that it is underutilized since there are so many other food products that could be made, such as fermented preparations, bread and breakfast cereals as indicated in the literature reviewed. The crop, properly utilized (not to mention industrial uses) could contribute significantly towards more food for consumption and avoid famine, though some surmountable problems exist.

7.1.1 Methodology

The methods used in the study were currently accepted methods which largely validate the results with reservations as already indicated.

(a) In Vitro Methods

In vitro protein digestibility measured by the pepsin digestion method of Axtell *et al*. (1981) used in this study approximated sorghum protein digestibility by young Peruvian children though malnourished (MacLean *et al*. 1983). Similar observations were made on sorghum based diets among 10-11 year old Indian boys (Kurien *et al*. 1960) and young girls (Daniel *et al*. 1966) and Nigerian young men of low income (Nicol and Phillips 1978). Similar *in vitro* sorghum protein determination gave close results (Armstrong *et al*. 1974) and in other foods correlated well with human values (Bodwell *et al*. 1980).

The *in vitro* iron availability method of Narasinga Rao and Prabhavathi (1978) is relatively new but the high correlation with humans, obtained by the authors, makes the method credible. This was supported by other results using the method or related methodology (Prabhavathi and Narasinga Rao 1979, Sankara Rao and Deosthale 1983 and Miller et al. 1981).

(b) In Vivo Methods

The in vivo studies using rats as models to predict nutrient availability to humans or at least give an indication, is currently accepted. The method has been widely used for protein nutritional value of sorghum and other foods (Hegsted et al. 1968, Eggum et al. 1973, Satterlee et al. 1979, Bodwell et al. 1980 and Eggum et al. 1983). The results have been consistent and reproducible. The same argument would apply to a lesser extent in in vivo iron availability studies using anaemic rats (Narasinga Rao et al. 1977), Schricker et al. 1981, Park et al. 1983).

(c) In Vitro Vis-a-vis In Vivo Methods

In vivo methods are expensive and laborious and they give indications acceptable within limits (Mariani and Spadoni 1979 and Saterlee et al. 1979). In addition, in spite of the arguments in favour of rat bioassays, this method has drawbacks as shown in our in vitro protein digestibility results. In vitro protein digestibility for the cooked dehulled low-tannin sorghum varieties was 43% while rats gave values of over 90%. The value of MacLean et al. (1981), of 46% on young children was much closer to our in vitro value and that of Mertz et al. (1984). Svanberg et al. (1984b) on Ethiopian young children had similar results in vivo. This demonstrated that the rat could not differentiate between raw and cooked low-tannin sorghum protein digestibility. The same argument would apply to dehulled and whole low-tannin sorghum flour (Tables 31, 34 and 35).

The rat bioassays using high-tannin sorghum gave consistent low protein digestibility closer to the in vitro method, so the rat model might be acceptable for testing varieties which are high in tannin content.

(d) Viscosity Determination

Viscosity measurement gives an indication of water-binding capacity of a gruel (nutrient density) and thus gives information on dietary bulk properties. However, the use of instruments gives only objective results and these are difficult to translate into subjective reactions on humans which is likely to vary widely between individuals. In the absence of more reliable methods, the viscosity of cereal or starchy based foods (Diehl 1982), gives a good indication of dietary bulk.

Food intake measurements are even more tricky, especially where young children are involved, as they have to be fed. Frequent measurements may be required. Such data has its limitations, but differences can be minimized by statistical methods to give acceptable results as was the case in the present study.

7.1.2 Protein Content and Nutritional Value

The overall chemical constituents and nutrient availability in sorghum grain is comparable and in some ways superior to common cereal staple grains as shown in this study and work by several workers (Dogett 1970, Maxon and Rooney 1980, Butler 1982, Mukuru et al. 1982, Eggum et al. 1983 and Axtell et al. 1984).

Improvement in protein digestibility by dehulling and germination in some varieties by the removal of the fibre and/or tannin rich bran, was accompanied with physical loss and nutrient losses. Traditional sorghum dehulling lost 20% to obtain acceptable good flour. Abrasive milling gave equally good flour with 10% physical loss, implying that abrasive milling was superior. In high-tannin sorghum the physical loss was offset by higher digestibility and Net Protein Utilization compared to the whole flour.

The nutrient losses due to dehulling, especially the limiting amino acid lysine result in lower protein biological value. The loss in vitamins especially the B group and mineral losses, in particular iron, imply worsening the protein energy malnutrition (PEM), vitamin deficiency diseases and anaemia in the predominantly sorghum staple areas, worse still where young children are weaned on mere sorghum gruels.

During food shortage periods, to extend the use of available sorghum grain as practised in Singida, Dodoma and other regions, the grain is milled whole for food preparation. This has serious nutritional consequences: low digestibility and nutrient availability in the prepared food as all the fibre and the tannins in the high-tannin varieties are ingested. The sorghum starch-protein matrix is tightly bound in sorghum flour which has a high gelatinizing temperature, 75-80°C (Akingbala et al. 1982), thus necessitating a long cooking time (Subramanian et al. 1982) and much fuel. This lowers total digestibility and nutrient availability as shown in this study and by others (Glennie et al. 1982, Price et al. 1980), thus worsening nutritional consequences on sorghum consumers.

However, in practice these problems are alleviated by consuming the low lysine grain with rich sources such as legumes and oil seeds (Ågren et al. 1975), or animal products when available. In a properly balanced sorghum diet thus nutrient availability would improve if enough food is eaten. This has been well documented in a review on "Protein Enriched Cereal Foods for World Needs" edited by Miller (1969).

On the other hand, some vegetables and legumes especially beans and peas are high in antinutritional factors such as tannins (Martin-Tanguy et al. 1977, Price et al. 1980, Rao and Desthale 1982), phytates (Erden 1979, Singh and Krikorian 1982) and much dietary fibre (Kelsay 1978, Theander 1983) as well as enzyme inhibitors in legumes (Sudhkar Prabhu et al. 1984) and chickpeas (Singh 1984). These, if not treated to low levels, might make dietary sorghum nutrients less available since enzyme inhibitors also occur in sorghum. Most of the inhibitors present in common cereals and pulses are heat resistant and may not be completely removed or deactivated by ordinary preparation and cooking procedures (Granum 1979, Jaffe et al. 1973).

The above mentioned is particularly important in boarderline food intake situations which predominate in rural Tanzania as reported in food consumption surveys by Maletnlema (1974) and review of food production during droughts between 1971-1975 (Bavu and Chale 1975). Maximum body utilization of ingested nutrients would be highly desirable especially where body losses occur due to disease and intestinal parasites which have been widely reported in Tanzania especially among children, expectant and lactating mothers (Maletnlema and Bavu 1974, Maletnlema 1976, Kimati 1977 and 1979).

7.1.3 Iron Content and Availability

The prevalence of dietary anaemia in sorghum staple regions in Tanzania (Table 4), while iron content of sorghum was reportedly high (Table 27) could be explained partly by the presence of contamination iron which is largely unavailable to humans (Hallberg et al. 1981, Hallberg et al. 1983). This observation indicates that food iron content from routine analysis gives artificially high values, divorced from real bioavailability.

Common dietary practices among sorghum consumers such as the consumption of vitamin C rich fruits such as citrus fruits, baobab fruit, guava and lightly cooked green vegetables with high iron content (Platt 1962) might provide more iron and enhance availability as reported in the literature (Gillooly et al. 1983, Gillooly et al. 1984).

However, iron availability might be severely reduced by tea as reported in human subjects fed maize porridge (Derman et al. and MacPhail et al. 1981). This may be serious especially where mothers give their children black tea as a substitute to weaning formulae. This is becoming increasingly common among urban low income mothers in Tanzania (Bantje and Yambi 1983). In the whole diet, total iron might also be made less available by interfering food components such as tannins, phytates and fibre as already stated.

7.1.4 Dietary Bulk

The viscosity of weaning foods have been shown to determine the total amount of food eaten in particular if the young children eat by themselves. High viscosity would obviously limit the amount of food eaten. Time is a constraint in busy village life and where a mother feeds a child, high viscosity preparations would take a longer time.

In the village study, bulk reduction by the use of "power flour" was accepted possibly because we used an indigenous technology to tackle an appreciated problem. The approach involved the existing political, social and traditional infrastructure with minimal outside interference, but with full participation by all concerned. The extra advantage of reducing the dietary bulk of improved, high nutrient weaning foods, provides a promising nutrition intervention whereby a child could double or triple its nutrient intake in a single meal, compared to usual, thin high bulk gruels, and meet required daily nutrient intake.

On germination in particular, the viscosity reducing effect by using germinated cereals for preparing gruels intended for feeding infants and young children as found in this study and earlier reported by others (Ljungqvist et al. 1981, Brandtzaeg 1981 and Desikachar 1980), is also recognized in traditional food processing in some communities in India (Brandtzaeg 1979) and in Tanzania (Chisawilo and Wandema 1980). One might ask why this beneficial practice is not more widely used, considering that the technology and raw materials are common in most village situations, at least in sub-Saharan Africa. One reason may be that the preparation of germinated flours is a rather time-consuming operation and if the work-burden of women is already heavy (Brandtzaeg 1981, Eresund and Tesha 1979), new tasks may not easily be accepted. In such cases, our proposed method of using germinated flour as an additive to liquify the prepared gruel may be a viable option, because germinated flour needs to be prepared less often and small portions can actually be set aside when local beer is produced. There is also reason to believe that other preparations that have amylolytic activity such as fermentation, can be used for reducing the viscosity of starch- based gruels in the same manner as we have described for germinated cereals. These could also easily be prepared and used at village/household level, and open up further possibilities of promoting high density weaning foods in starchy staple areas.

7.2 General Conclusions

7.2.1 Chemical Composition

(a) The sorghum varieties studied, white low-tannin (ET35-1 and Lugugu), brown high-tannin (5DX 135/13/3/1 and Udo Msonga), resemble other cereals in chemical composition and could provide good sustenance as has been the case for centuries in the semi-arid tropics (SAT).

(b) The essential amino acid, lysine, was limiting and along with other nutrients (protein, fat and minerals) and antinutritional factors: were more reduced by traditional dehulling (mortar and pestle) than abrasive decortication. Germination significantly increased lysine content.

(c) Dietary fibre was higher in the high-tannin varieties than the low-tannin types. It was reduced by dehulling but not by germination.

(d) Contamination iron was reduced by the washing effect during the germination procedure.

(d) The vitamin B content was significantly increased by germination.

(f) The antinutritional factors tannins and phytates were high in the brown varieties and were reduced by dehulling and germination to different degrees.

7.2.2 Nutrient Availability

(a) In vitro raw sorghum protein digestibility was high for the ungerminated low-tannin varieties and lower for the high-tannin varieties. Germination improved digestibility highly significantly in the low-tannin varieties and to a smaller extent in the high-tannin varieties.

In vitro iron availability was generally low in the ungerminated low-tannin raw varieties and lower still in the high-tannin varieties. Germination lowered iron availability except in one of the high-tannin varieties 5DX. Tannin content negatively affected both protein digestibility and iron availability.

(b) In vivo protein digestibility using weanling rats was high for the cooked low-tannin varieties, but very much lower for the high-tannin varieties. Germination improved digestibility only in one high-tannin variety (Udo). Generally biological value (BV) and net protein utilization (NPU) were not affected by germination.

In vivo iron availability in weanling rats was variety dependent (high in ET35), low in all other varieties. Germination increased iron availability only in one high-tannin variety - 5DX.

In both protein nutritional value and iron availability, tannin content negatively affected the values.

In vivo zinc availability was low in all varieties and was unaffected by germination or tannin level.

Enzyme inhibition by raw sorghum extracts was only observed in the low-tannin variety Lugugu on human salivary and pancreatic amylase, but the high-tannin varieties, germinated and ungerminated, stimulated these enzymes. Trypsin was not inhibited but chymotrypsin was.

(c) Dietary bulk

Germination reduced the viscosity of weaning gruels, highly significantly in the low-tannin varieties through the production of amylolytic enzymes. Bulk reduction of gruels was also achieved by adding 5% germinated flour of sorghum to cold or hot cooked thick gruels. A similar effect was achieved by mixing the ungerminated and germinated flour, with the right amount of cooking water and keeping overnight.

The simple technique of reducing bulk by using "power flour" was accepted by mothers at village level and adopted at home for preparing weaning gruels. Food intake of preschool children was age dependent, but during the critical weaning period, between 12 and 48 months, bulk reduction increased food intake significantly over local conventional high bulk gruels.

In final conclusion, our initial hypothesis that germination would improve sorghum nutrient availability and reduce dietary bulk was proved correct in most of the aspects studied in the four sorghum varieties. Protein digestibility and nutritional value increased, dietary iron increased in one variety, antinutritional factors were reduced, and viscosity of weaning gruels was highly significantly reduced. The method of bulk reduction through germination was accepted, used at village level and increased food intake and hence nutrient intake by young preschool children.

7.3 Recommendations

The recommendations are made with brief reasons to justify them based on literature and experimental results from the present study.

7.3.1 Practical Recommendations

(a) Sorghum is generally a good food source for human use. Higher production should be encouraged to use this drought resistant crop to stem off food shortages and famine. Proper storage and handling should be followed as recommended (Mosha 1983).

(b) Traditional practices on sorghum food preparations, including dehulling, milling, cooking and accompanying additives, relishes or mixtures, should be revived or reinforced. Furthermore, new product development of acceptable and convenient sorghum foods for wider and more varied use of sorghum could be undertaken soon.

(c) Farmers should be encouraged to produce more low-tannin varieties for food since they are nutritionally superior to high-tannin varieties. Where vermin birds damage threatens, high-tannin varieties will require proper dehulling to overcome antinutritional factors.

(d) With regard to dehulling and milling into flour, light bran free sorghum products are important for acceptability. Small batch mills in villages and larger industrial mills in towns, sepcially adapted for sorghum and other cereals would be highly desirable.

(e) Bulk reduction of weaning gruels by using suitable germinated cereals should be encouraged and promoted among mothers using existing infrastructure, so as to increase nutrient intake by young children and alleviate malnutrition.

7.3.2 Recommendations for More Research Work

There are several issues that were not fully resolved in the present study or aspects of interest which were noted for further investigation.

(a) More thorough investigation and documentation of traditional sorghum food preparation methods would shed light on how they have sustained the population for centuries, where sorghum is used as a major staple, inspite of the observed nutritional limitations.

(b) A study of sorghum eating habits in relation to nutritional status, with special attention to the composition of integrated foods, would form a basis for further studies using *in vitro* and *in vivo* methods. This will enable us to understand better how sorghum is best used for food.

(c) Chemical composition and nutritional value of more Tanzanian local and improved varieties should be undertaken since this study covered only four out of the hundreds of varieties in the country.

(d) The issue of sorghum protein digestibility which is to date still controversial, requires deeper study so as to understand the effects of the seed constituents such as tannins and the fibre fraction and how they behave in vitro and in vivo.

(e) Sorghum tannins and polyphenols which might be agronomically desirable but detrimental to digestion and nutrient availability warrant special attention with emphasis on their identification, physiological role and removal or inactivation.

(f) Work on developing new methods for dehulling sorghum at village level, introducing and promoting them for widespread use would decrease druggery and encourage efficient utilization of sorghum. The same argument would apply in urban areas on a larger scale, but with related industrial products such as malt, starch, glue, alcohol and fuel.

(g) It would be desirable to further study sorghum germination for its positive effect on nutrient availability and its activation of amylolytic enzymes.

(i) Finally, introduction and promotion of the use of "power flour" in more villages should be done. Preschool children, food intake studies under controlled conditions or typical household environment along with contributory factors, might increase knowledge on dietary bulk and energy density in relation to nutritional status.

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