INVESTIGATIONS ON THE NUTRITIVE VALUE AND PRACTICAL WAYS OF FEEDING CASSAVA ROOTS TO PIGS

BY

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ABSTRACT

The study was conducted to evaluate the feeding value of cassava roots in four growth and two metabolic experiments. In the growth studies, feed was offered *ad libitum* except protein supplement to pigs fed fresh cassava tubers. The pigs were group fed and slaughtered as they reached 90 kg liveweight. Carcass characteristics and organ weights were determined. Cassava had no significant effect on growth rate, organ weights, gut fill or carcass characteristics.

In experiment 3 and 4, a comparison was made of the commercial sow and weaner (SW) meal, cassava root meal (CRM) diet, soaked cassava root tubers (CRT) diet and rice polishings (RP) diet. The average daily gains were 625 g, 635 g, 609g and 660 g, and feed conversion ratios (kg DM feed/kg gain) 4.44, 4.19, 4.05 and 3.89 for the SW diet, CRM diet, CRT diet and RP diet, respectively. The average daily feed intake (kg dry matter) was 2.58kg, 2.55 kg, and 2.47 kg for pigs fed the SW diet, CRM diet CRT diet and RP diet, respectively. Pigs fed soaked cassava root tubers consumed 3.5 kg cassava/pig/day and required 406 kg cassava tubers and 152 kg protein supplement form 20 to 90 kg liveweight.

In experiment 5, cassava root meal and cassava root tubers were again compared with cottonseed cake as the main protein source or a combination of cottonseed cake and sunflower cake.

Daily gains feed intake and feed conversion ratio (kg DM/kg gain) were 551 g, 638 g, and 589 g, 1.87 kg, 2.10 kg, and 2.03 kg, and 3.45, 3.36 and 3.56 for CRT + sunflower cake diets, CRM + cottonseed cake, CRM + cottonseed cake + sunflower cake diets respectively. Pigs fed fresh cassava root tubers consumed 2.97 kg cassava/pig/day and required 383 kg cassava and 112 kg protein supplement from 20 to 90 kg liveweight.

Experiment 6 was designed to examine the voluntary feed intake, growth rate and feed conversion of pigs fed a diet considered as a standard cassava diet (2/3 cassava, 1/3 protein giving a 15% CP diet) under Tanzania conditions. Feed intake was about 30% higher in the ad lib. fed barrows than in the ad lib. fed gilts and restricted barrows and gilts, while growth rate was about 23% higher.

It is concluded that cassava is a good energy source for pigs, and where it is relatively cheap and abundant, it could be used as the only energy source in diets of growing-finishing pigs and cottonseed cake could form the major part of the protein supplement.

DECLARATION

I, Faustin Paul Lekule, do hereby declare to the Senate of Sokoine University of Agriculture that the thesis presented here is my own original work and that to the best of my knowledge this work has not been submitted to any other University for a degree award.

Signature ____________________

Date ____________________

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CHAPTER 1

INTRODUCTION

The pig industry has received less attention in the developing than in the developed countries despite the fact that 57% of the world pig population is found in the former countries (FAO, 1983b). Consequently, the contribution of pigmeat to the economy and diets of people living in the developed countries is very high, while it is very low in the developing countries.

Pigmeat production from the developed countries is 35 million tons/annum, while it is only 19 million tons from the developing countries (FAO, 1983b).

Improvement of the productivity of pigs has been achieved in a relatively short period of time in the developed countries viz. through improved nutrition, management, breeding and disease control. This improvement has been possible due to the various attributes of pigs, i.e. fast growth, great ability to convert concentrates to meat, prolificacy, and short generation interval.

On the other hand, the survival of the pig in many of the developing countries has been due to its voracious appetite, which enables it to consume almost any feed, great adaptability and hardiness. Not many of these countries can afford to feed cereals to pigs, because grain production falls short of demand for human consumption.

Pig production is not a major enterprise in Africa. Whereas the world pig population stands at 774 million, there are only 11 million pigs in Africa (FAO, 1983b). Meat production from these pigs amounts to only 392,000 tons. Numbers of pigs in Tanzania are estimated to be 296,000 (Ministry of Agriculture and Livestock Development, 1984).

The small population of pigs and low productivity in Tanzania, and indeed in other African countries, is attributed partly to shortage of concentrates, lack of tradition of keeping pigs by peasant farmers, large areas of pastureland unsuitable for permanent cropping, and the influence of muslims. With a land area of 88.6 million hectares, only five million hectares are under arable and permanent cropping in Tanzania (FAO, 1983b). About 35 million hectares are under permanent pasture. The human population is 22 million people.

Most of the pig producers in Tanzania are small-scale producers, who keep a few pigs in low cost houses and feed them on swill, brewery waste and grass. Where agro-industrial by-products such as oilcakes and grain milling by-products are available, farmers sometimes purchase and use these commodities if it is economically feasible. Production of commercial pig feeds is not a priority, and less than 3,000 tons are produced every year. These feeds are based on maize and sometimes sorghum. Imported yellow maize is commonly incorporated in these feeds. The fact that maize and sorghum form the staple food of many Tanzanians explains why there is a critical shortage of commercial pig feeds, as well as of other livestock feeds in the country.

As the human population grows, marginal lands, which have, so far, been used for grazing, will have to be cultivated. A move towards keeping animals suitable for intensive systems will take place. Crops 'suitable' for these marginal lands will be the crops of choice. Cassava could become a food crop as well as a cash crop in such areas.

Cassava, which is widely grown all over the country, seems to offer a suitable source of energy for pigs, as well as a suitable substitute for the costly maize in commercial pig compounds. Cassava is drought resistant, is relatively resistant to pests and diseases, withstands hazards like locusts being a root crop, requires no fertilizers, has no peak labour requirements, has a high yield of calories, can be stored in the ground (tubers) until required, and has no critical time of planting or harvesting as is the case with cereal crops. These advantages are very important to the peasant farmers.

In Tanzania, cassava is used in various ways and forms as a food for humans. The roots may be peeled and eaten raw, fried or roasted as snacks. They can be boiled and eaten as a vegetable, dried and later ground into flour, or fermented and later on milled after drying. Hitherto, cassava has been confined to use as human food and for export, but there is no doubt that cassava offers a practical feed energy source for pig farmers in Tanzania and even more so than any other crop.

The feeding value of cassava roots has been investigated by many workers (Oyenuga and Opeke, 1957; Modebe, 1963; Maner et al., 1967; Montilla, 1976; Gomez, 1977; Khajarern et al., 1977). In Tanzania, most of the work on cassava utilization has been conducted at Sokoine University of Agriculture (Wyllie and Lekule, 1980; Babyegeya, 1980; Kakala, 1981). Khajarern et al. (1980a) demonstrated that cassava could totally replace maize in pig rations, and that such substitution was simple and sufficiently easy to handle for any pig producer on the farm thus avoiding resort to feed millers.

The objectives of the present studies were:

a. To find the optimum level of replacing maize by cassava root meal in diets of growing-finishing pigs;

b. To study the effect of using cassava roots as the only source of energy for pigs as compared to other feeds;

c. To examine possible sources of protein for formulating pig diets based entirely on cassava;

d. To study the effect of plane of nutrition and sex on performance of growing-finishing pigs fed a standard cassava diet, and

e. To develop simple and practical ways of feeding cassava roots to pigs.

CHAPTER 2

LITERATURE REVIEW

2.1 The status of pig production in Tanzania

Early surveys on pig production have given different and somewhat contradictory figures. Some of these figures were based on projections. It is difficult to correctly predict the population of pigs, and, due to the many factors involved, pigmeat production and demand in a country with a rapidly growing human population.

The Marketing Development Bureau (1972) indicated a total of 16,000 and 28,000 pigs in 1965 and 1972, respectively. Steengaard and Shoo (1973) estimated the pig population to be 62,000 in 1973. Later data collected by Shaw et al. (1980) gave a total population of 81,000 pigs. Hiemstra (1981) and FAO (1981) have given a figure of 165,000 pigs. For 1983, the figure given by FAO is 175,000 pigs. The amount of meat produced from these pigs was estimated to be 5,000 tons from 126,000 carcasses.

Hiemstra (1981) has forecast production targets as shown in Table 2.2. The contribution of pigmeat was estimated at 2.6% of the total meat produced and consumed.

Pigs were brought to Tanzania (then Tanganyika) during the colonial rule, and hence there is no evidence of the presence of a native breed. When reference is made to 'local pigs', these are, in fact, pigs imported into the country a long time ago and consequently well adapted to local conditions. In most cases these pigs are Large

Table 2.1 : **Pig population trends (In thousands)**

Year	1920	1925	1935	1945	1955	1965	1973	1979	1981	1983	1984
Numbers	2.0[1]	3.0[1]	8.5[1]	7.3[1]	12.5[1]	20.5[1]	62.0[2]	81.0[3]	165.0[4]	175.0	296.0[5]

1. Ministry of Agriculture (1969)
2. Steengaard and Shoo (1973)
3. Shaw *et al*. (1980)
4. FAO (1981, 1983b)
5. Ministry of Agriculture and Livestock Development (1984)

Table 2.2 : **Pigmeat - production targets (Hiemstra, 1981)**

	1981	1990	2000
<u>Traditional sector</u>			
Pig population, nos.	152,500	186,250	210,000
Offtake, percent	40	68	80
Carcass weight, kg	64	60	60
Production, metric tons	3,900	7,560	10,080
Annual increase, %		7.6	2.9
<u>Commercial sector</u>			
Pig population, nos.[1)]	12,000	30,000	40,000
Carcass weight, kg	70	60	60
Production, metric tons	840	1,800	2,400
Annual increase, %		8.8	3.3
Total production, metric tons	4,740	9,360	12,480
Annual increases		7.9	2.9

1) A 100 percent offtake is assumed

Whites.

For the same historical reasons, most of the pigs are kept in highland areas with a cool climate. In the traditional peasant farmer systems, the productivity of pigs is very low - mainly due to poor nutrition and husbandry. In some of these highland areas, however, pigs provide meat and cooking fat (lard) for the population. Also, they are a source of income and provide manure for the fields.

Due to the fact that meat production can be increased relatively fast from pigs, a large number of small pig units have emerged in peri-urban areas. The demand for pigmeat is high and is increasing with the rise in the human population. It may not be very surprising that the pig population has increased more than ten-fold in the past 20 years. Obviously, with the increase in the human population less land is available for extensive grazing of ruminant animals. People then shift towards confinement rearing of animals, and pigs are best suited to this system as is clearly shown by the concentration of pigs in the densely populated areas, while very few pigs are kept in the sparsely populated areas.

Feed costs account for about 70 - 80% of the cost of raising pigs. The major components of feed are energy and protein. While most of the protein can be derived from oilcakes, energy can be provided by cereals and their by-products and root crop tubers. A variety of oilcakes are produced in Tanzania. In 1983 Tanzania exported 24,500 tons of oilcakes of which 21,000 tons were cottonseed cake (FAO, 1983b). These oilcakes are fairly cheap, and, in most cases, prices are lower than those of cereals.

Oilcakes could be used as a cheap source of protein in pig feeds. Without a reliable source of energy, pig production cannot be sustained and modernized. An efficient pig industry cannot rely on swill or brewers' waste as supplies are erratic and the nutritive value of the products unreliable. With the increase in pig numbers and pig units, efficient methods of production are required. Efficiency and economy of production can be greatly improved by the use of fairly well-balanced rations based on a cheap and abundant energy source. The prices paid to farmers by the National Milling Corporation (NMC), the sole national body responsible for buying and selling food crops, are shown in Table 2.3. The price of cassava is the lowest one while yield and total production of cassava show the highest figures.

2.2 Cassava and its importance in Tanzania

Cassava (*Manihot esculenta, Crantz,* or *Manihot utilissima,* Pohl), also known as tapioca, manioc, mandioca or yuca, is a root crop widely grown in the tropics. The world production of cassava is 127 million tons, of which 21% is harvested in Brazil, 11% in Thailand, and 10% each in Indonesia and Zaire (Khajarern and Khajarern, 1984). Africa produces 48 million tons, which is 39% of world production, and Tanzania produces 6.8 million tons, which is 5.5% of world production and 14% of production in Africa. Out of the total arable land of 4 million hectares, 1.3 million hectares are used for cassava, corresponding to 32.5% of the total arable land.

Table 2.3 : **Crop and crop by-products production in 1983 (FAO, 1983a,b) and prices of some foods in 1986 in Tanzania**

Crop	Total production (metric tons)	Yield (kg/ha)	National Milling Corporation purchase (Tshs/kg)
Maize	2,000,000	1183	6/30
Paddy			9/60
Wheat			7/20
Cassava	6,800,000	5231	3/60
Sorghum	220,000	629	4/80
Bulrush millet			4/80
Beans	154,000	497	14/40
Soya beans	1,000	240	11/30
Millet	150,000	682	
Groundnuts (in shells)	58,000	604	
Sesame seed	18,000	292	
Sunflower seed	42,000	525	
Cottonseed	109,000		
Copra	29,000		
Coconuts	320,000		
Cashewnuts	35,000		

Cassava is the topmost tuber crop growth in the tropical countries, and indeed in Tanzania. It is a staple food for masses of poor people in the underdeveloped countries of the tropics (Devendra, 1977: Ravoof et al., 1977). About 500 million people depend partly or wholy on cassava for their daily food.

Cassava has peculiar comparative advantages as a tropical crop. These have been listed by Lekule (1986) as:

a. Reasonable yields in areas of little and unreliable rainfall.
b. Tolerance to acidic and poor soils.
c. Relatively high resistance to many pests and diseases.
d. Low time specificity of planting and harvesting.
e. High potential yield of calories per hectare.
f. Low cost of production. No inputs like fertilizers are necessary.
g. Vegetative propagation. Planting material does not constitute part of the edible matter and ensures preservation of desired characteristics.

These attributes of cassava have been responsible for its popularity, especially in Africa where 52% of the arable land is devoted to cassava. Hahn (1986) has documented that since its introduction in the 16th century, cassava has brought about great changes in the cropping systems in Africa. This was attributed to its adaptability to low input, mixed cropping systems, poor and acidic soils, and a wide range of environmental conditions.

The average annual per capita consumption of fresh cassava over the past 10 years in Africa was 116 kg, as compared to 23kg for South America and 21kg for the world (Hahn, 1986). Individuals in

Africa received 350 calories per day from cassava during the past 10 years.

The roots of cassava are an important source of dietary carbohydrates, while the leaves are rich in proteins and vitamins (Onwueme, 1978). In Tanzania, in areas where other crops like maize, paddy and bananas are grown, cassava is considered an inferior food crop. Consequently, there is a tendency for its consumption to be limited to people either of low income, who cannot afford the high-priced grains like rice and maize, or who cannot grow other food crops due to adverse climatic conditions.

There is a clear and undisputable demand for sweet varieties of cassava. The colour of the tuber peel is also important. In areas, where cassava is the staple food, the bitter varieties are predominant. The tubers of the sweet varieties can be peeled and eaten raw, roasted or fried as snacks or boiled. Cassava flour can be produced from peeled and dried cassava tubers. The flour is used for making stiff porridge -"ugali". The bitter varieties have to be fermented and dried before preparing cassava flour. Sun drying is the common way or drying. Cassava leaves are pounded in a mortar, boiled and eaten as a vegetable - "kisamvu".

The importance of cassava has long been realized in Tanzania. The earliest breeding work on cassava in East Africa was started in 1937 in Amani, Tanzania. Varieties resistant to cassava mosaic virus have been bred and distributed all over East Africa and as far as Nigeria. These varieties were bred by Storey (Nichols, 1947) by interspecific crossing between cultivated cassava (**M. esculenta**) and a related species (**M. glaziovii**). He obtained 20 F_1 plants. These were further backcrossed. A selected clone, 58308, still remains resistant to cassava mosaic virus. The leaves of **M. glaziovii** are commonly used as vegetable (Kisamvu). In 1980, it was reported that the regional yields of fresh cassava tubers in Tanga were between 5 and 10 tons/ha. By using the high yielding varieties bred - 46106/27 and 4763/63 - yields ranging from 15 to 25 tons/ha. were obtained (Anon., 1980). Much higher yields have recently been reported by Hahn (1986), who stated that selections from IDRC/FAO supported projects gave yields of 30 - 35 tons/ha compared to 15 tons/ha from local varieties in Tanzania.

Table 2.4 shows the production trend of cassava in Tanzania. It is possible that if high yielding varieties are publicised and distributed throughout the country, much higher yields will be realized.

The acreage under cassava is increasing at the rate of 10,000 ha/year, while yields are increasing by 50,000 tons/year. Like many of the other food crops, cassava is grown mainly at the subsistence farming level. Most farmers grow cassava for domestic consumption and sell the excess. This is reflected in Table 2.5 which shows erratic purchases of cassava roots.

Cassava has been grown in Tanzania on a subsistence scale for many years. Despite the fact that substantial work has been done to improve its production, the crop continues to be considered an

Table 2.4 : **Cassava production trends in Tanzania (FAO, 1983b)**

Year	Area harvested 1000 ha.	Yield kg/ha	Production 1000 metric tons
1967 - 71	695	4854	3373
1979	930	4892	4550
1980	940	4894	4600
1981	950	4895	4650
1983	1300	5231	6800

Table 2.5 : **Recent trends of purchases of cassava by National Milling Corporation**

Year	Quantities (metric tons)
1974/75	18,621
1975/76	17,635
1976/77	19,746
1977/78	36,937
1978/79	63,767
1979/80	44,015
1980/81	7,516
1981/82	9,223
1982/83	18,764
1983/84	30,687
1984/85	19,824

inferior crop and a 'famine reserve' to be consumed by the poorest people. Jones (1959) quoted the Dodoma Provincial Commissioner in 1943: 'It has been found that the growing of cassava, the anti-famine reserve in most provinces, cannot be recommended here ... stock, vermin, white ants and the people themselves are against it'.

The use of cassava in commercial livestock feeds is almost non-existent. Only recently, at a time of food shortage, cassava was included in livestock feeds compounded by the national feed company - Tanzania Animal Feeds Company (TAFCO). This inclusion of cassava met with disapproval from livestock keepers, especially poultry farmers. It was during this same period that the NMC got rid of large stocks of cassava roots for human consumption to alleviate the food shortage.

Inclusion of cassava in livestock feeds is considered uneconomical because of the unrealistic and artificial price structure. In 1984 the price of cassava (as sold by NMC) was Tshs. 5,300 = per ton - slightly higher than the price of maize. In 1986, the price was Tshs. 8,600/= per ton. This was less than the price of maize but sufficiently high to discourage TAFCO from using it. The NMC on their part pay only 3,600/= per ton to cassava growers. Had it not been for the Government subsidy to TAFCO, cassava could be procured direct from the farmers or through the cooperative unions thus making it possible to produce cheap livestock feeds. It has been natural to use rice and wheat in livestock feeds in times of shortage of maize, despite the high price level of the two cereals. Imported maize is commonly used in livestock feeds. TAFCO is under pressure to produce large quantities of good quality animal feeds.

The company tries to do so by using good quality cereals, as the market price does not reflect the cost of production due to Government subsidization. Other small feed mills, have therefore, been unable to compete as they have no access to cereals procured by TAFCO, and consequently prices of feeds from these mills are prohibitive. Together with its handling problems, cassava has been left to the NMC who have had to find possible export outlets.

Another problem posed by cassava is its low protein content. This necessitates the use of higher levels of protein supplements. Cottonseed cake is most abundant and, due to low production of soyabeans, soyabean cake is not produced. Due to the gossypol toxicity of cottonseed cake, its inclusion is usually limited to 10% in commercial compounds. Cassava based diets would require high levels of animal protein, and this is very expensive.

The dustiness of cassava meal presents a problem to millers. The conveyer system in many mills is unsuitable for powdery feeds. Cassava in the form of chips or meal is bulky and hence requires more space than grain. This increases the cost of handling, transportation and storage.

The use of cassava by small-scale pig farmers has not been widespread, as the main cassava growing areas are found in the dryland districts where farmers have no tradition of keeping pigs. In places where cassava is not the staple food or extensively grown, prices of fresh cassava - the normal method of marketing - are too high for it to be used as a pigfeed.

On a global basis, cassava has steadily increased its share in the animal feed industry. The European Economic Community (EEC) has been the most important market for cassava products. Thailand, on the other hand, has been the largest exporter of cassava, mainly in the form of chips and pellets.

EEC imports of cassava pellets have increased from 2.3 million tons in 1975 to 8.8 million tons in 1982. In 1985 imports declined to 5.9 million tons. Thailand's share of EEC imports rose from 2 million tons in 1975 to a peak of 7.4 million tons in 1982 and then declined to 4.9 million tons in 1985 (Boccas, 1987). In 1982 total EEC imports of cassava for the food industries amounted to 16.5 million tons.

Owing to the special characteristics of cassava, efforts by many international organizations working on improvement of cassava production, and the climatic adversities in many parts of Tanzania, cassava seems to be the crop of the future both as human food and livestock feed. Ravindran et al. (1983) have pointed out that the ability of cassava to grow under suboptimal conditions - soils, climate and husbandry - makes it competitively superior to maize. These are the most significant aspects to consider in an evaluation of the role of cassava in tropical animal feed production systems.

2.3 Yield of cassava tubers

Cassava is grown under varying edaphic and climatic conditions and hence its yield is very variable. World production is 8 tons/hectare (FAO, 1983b). This is higher than the figure of 5 tons/hectare reported by FAO (1983b) for Tanzania. Where cassava is well tended, yields of 24 tons/ha are common in South America, while yields of 50 to 100 tons/ha have been reported in individual plantings (Alvarez-Luna, 1972). One cultivar, 'Llanera' yielded more than 100 tons/ha in 10 months in rich, black soils. Average yields in Burundi, India, Thailand and Brazil have been reported to be 22.2, 16.5, 14.8 and 12.7 tons/ha, respectively (Montaldo, 1977). Differences of clones, edaphic conditions, cultivation practices, use of fertilizers and disease control influence these yields significantly (Montilla, 1977; Khajarern et al., 1977).

Improved varieties of cassava developed at Ibadan, Nigeria, by the International Institute of Tropical Agriculture (IITA) have given comparatively high yields. In Rwanda, these varieties yielded from 16.8 to 73 tons/ha in different locations, while in the Seychelles the best variety gave an average yield of 45 tons/ha (Hahn, 1986). In Gabon, yields ranging from 20 to 40 tons/ha were obtained, while in Sierra Leone yields ranged from 9.7 to 25.3 tons/ha (two to four times the yield of local varieties). In Zaire, a variety tolerant to waterlogging (Kinuani) yielded from 16.5 to 30.8 tons/ha compared with only 5.7 tons/ha for the standard variety. Montaldo (1977) concluded that with a 10 tons/ha root production and 25 tons/ha foliage meal production, 192 million tons of cassava products (50% from roots and 20% from foliage) could be produced from 11.1 million hectares. The author holds that if the feed was produced from cereals and oilseeds, 190 million hectares of good soil would be required. On the same basis, the area planted to cassava in Tanzania (1.6 mill. hectares) could produce 22 million tons of cassava products. With the average cereal yield of 1098 kg/ha (FAO, 1983b), it would require 20 million hectares of good soil to produce the feed from cereals.

It is apparent that the potential yield of cassava is very high, and the attention being focused on its improvement by organizations like Centro Internacional de Agricultura Tropical (CIAT), IITA, EEC and the International Development Research Centre (IDRC) may result in a tremendous increase in production.

2.4 **Chemical composition of cassava**

The approximate composition of mature cassava plant is: 6% leaves, 44% stems and 50% tubers, the latter being made up of 8% peelings, 11% water and 31% starch (Devendra, 1977). According to Onwueme (1978), the peel forms 10 - 20% of the weight of the tuber and is lower in dry matter content. The fresh root contains about 32% dry matter, 89% N-free extract, 0.09% ether extract, 5.1% crude fibre, 2.2% crude protein and 2.8% ash (Jalaludin,1977).

The proximate composition of cassava root has been determined by many workers (Oyenuga, 1955; Johnson and Raymond, 1965; Naik, 1967; Mensa et al., 1970; Hutagalung, 1972; Muller et al., 1972; Maner, 1974; Montilla, 1976; Montaldo, 1977; Babyegeya, 1980; Wyllie and Lekule, 1980; Eggum and Kategile, 1981; Kakala, 1981). Some of these analyses are contained in Table 2.6 and 2.7.

Table 2.6 : **Proximate composition of cassava from Tanzania, percent of dry matter**

Feed source	Peeled dry tuber[1]	Whole dry tuber[2]	Peeled dry tuber[2]	Peeled fresh tuber[3]
Dry matter	88.56	98.19	97.29	35.00
Crude protein	2.04	3.38	2.25	2.90
Crude fibre	2.42			8.54
Ether extract	0.40			1.91
Ash	1.94	3.26	2.76	
NDF	10.11			
ADF	4.22			
Cellulose	2.63			
Lignin	1.60			
<u>Gross energy:</u>				
MJ/kg	16.94			
Ca	0.08			
P	0.06			

1 Wyllie and Lekule (1980)

2 Eggum and Kategile (1981)- Mzungu variety

3 Kakala (1981) Mzungu variety

Table 2.7 : Proximate composition of cassava from other parts of the world, percent of dry matter

Feed source	1	2a	2b	2c	3	4	5
Dry matter	87.60	31.94	28.50	31.94	87.00	87.90	89.00
Crude protein	3.60	2.71	2.58	2.38	1.40	2.50	2.60
Crude fibre	4.40	3.09	0.43	1.93	2.50	3.50	3.00
Ether extract	1.10	0.53	0.46	0.65	0.40	0.30	1.30
Ash	6.40	2.66	2.41	2.89	2.30	1.80	1.80
NFE	84.50	91.01	94.12	92.12	80.40	79.40	91.20
Ca	0.24						0.04
P	0.12						0.04

1 Just et al. (1983a) - cassava root meal

2 Oyenuga (1955a) - unpeeled bitter variety tubers

(1955b) - peeled bitter variety tubers

(1955c) - unpeeled sweet variety tubers

3 Hansen and Sunesen (1973) cassava root meal

4 Muller et al. (1975) cassava root meal

5 Hutagalung et al. (1973) cassava root meal

2.4.1 Carbohydrates

Cassava is rich in starch and poor in protein, fat, minerals and vitamins. It is reported to contain 64 - 72% starch, of which amylose and amylopectin together constitute 99% of the dry cassava starch (Johnson and Raymond, 1965). The other important carbohydrate is sucrose, which can amount to as much as 17% in some cutlivars (Jalaludin, 1977). Starch constitutes the bulk of the soluble carbohydrates containing about 3.2 to 4.5% crude fibre and 95 - 97% nitrogen free extracts (NFE) (Hutagalund et al., 1973; Muller et al., 1975).

Studies in Tanzania have revealed starch contents of 89% (Wyllie and Lekule, 1980), while for the Mamboleo variety values of 77 to 81% were obtained by Raymond et al. (1941). However, the latter authors suggested the value of 70% carbohydrate as representative of Tanzanian cassava roots. But values obtained by Eggum and Kategile (1981) are higher. The values of readily soluble constituents of the Mzungu variety were 74.8% and 77.4% for whole cassava tubers and peeled tubers, respectively. Just et al. (1983a) have reported values of 85.5% and 76.6% for NFE and readily soluble constituents, respectively.

There are indications that the starch content is positively correlated with glucoside contents of the tubers (Seerly et al., 1972). Hence, high glucoside cultivars are usually high starch yielders. There is also some relationship between palatability and starch contents. Usually, the higher the starch content the lower the palatability. Thus bitter cultivars have a higher starch content and are higher in glucosides than sweet cultivars. However, the relationship between bitterness and glucoside content is not always constant (Gondwe, 1974). Also, Doku (1966) has indicated that tubers with higher starch had a better palatability, since they contain comparatively less fibre.

The NFE in the tuber contains 80% starch and 20% sugars and amides (Vogt, 1966). The starch contains about 20% amylose and 70% amylopectin (Johnson and Raymond, 1965). Oke (1978) stated that the high amylopectin content in cassava relative to maize makes it a more suitable source of energy for ruminants than for monogastric animals. According to Muller et al. (1972), the amylolytic activity of cassava meal is about one third of that found in maize and about half the level of rice bran. Whelan and Roberts (1953) explained that with amylose a linear starch molecule where the glucose units are joined only by α 1 - 4 links - the hydrolysis proceeds as if all links, except the terminal one at each end, were equally susceptible, and the terminal links are not totally resistant to salivary amylase.

Amylase is present in high concentrations in pig saliva and breaks down starch to maltose, maltotriose and dextrins. Amylase is also found in the pancreatic juice. With branch chain starches such as amylopectin and glycogen which consist of α 1 - 4 glucose chains joined to one another by α 1 - 6 branch links, the branch link and some links next to it are resistant to α-amylase hydrolysis (Roberts and Whelan, 1960). The authors explained that in addition to the production of maltose and maltotriose from the parts of the chain remote from a branch point, a variety of larger oligosaccharides

(α-limit dextrins) are produced, which may incorporate one or more α 1 - 6 branch links.

2.4.2 Proteins and amino acids

Cassava is very low in protein, and the protein is of poor quality. Jalaludin (1977) has documented that the nitrogenous substances vary from 0.7 to 2.6%. Lysine, methionine and tryptophan are very low, as shown in Table 2.8. In this respect, the amino acid profile compares unfavourably with that of cereal grains. Osuntokun et al. (1968) explained that both cystine and cysteine are involved in cyanide detoxication, and excessive cyanide detoxication may be responsible for low concentrations of sulphur containing amino acids.

Montaldo (1977) documented that the value for crude protein ranges from 3.93 to 10.05%, but refined cassava flour contained as little as 0.3% protein. The author noted that the peel contains a higher percentage of nitrogen than the fleshy part of the root.

That cassava is deficient in amino acids has been demonstrated by many workers (Close et al., 1953; Oyenuga, 1968; Hutagalung et al., 1973; Montaldo, 1977; Wyllie and Lekule, 1980; Eggum and Kategile, 1981). Although a 7.25% protein Columbian cultivar (Llanera) has been developed, the scope for improvement of protein content in casssava through agronomic and genetic manipulation seems to be limited (Pond and Maner, 1974). Its effect on HCN content and soil nutrient demand are not known.

Table 2.8 : **Amino acid content of cassava compared to other cereals, g/100 g feed**

	Cassava meal					Maize	Sorghum	Barley	Rice(polished)
	Muller *et al.* 1975	Eggum & Kategile 1981	Just *et al.* 1983	Wyllie & Lekule 1980	F.A.O. 1970	F.A.O. 1970	F.A.O. 1970	F.A.O. 1970	F.A.O. 1970
Protein, g	2.50	2.25	3.20	1.80	1.60	9.50	10.1	11.0	6.70
Lysine, mg	42.00	75.00	123.00	69.00	67.00	254.00	204.0	406.0	255.00
Methionine, mg	19.00	37.00	43.00	18.00	22.00	182.00	141.0	196.0	150.00
Threonine, mg	55.0	77.0	96.00	61.00	43.00	342.00	307.0	389.0	234.00
Tryptophan, mg	11.00		26.00		19.00	67.00	123.0	180.0	95.00
Total essential amino acids, mg					404.00	3820.00	3945.0	4203.0	2695.00
Total amino acids, mg					1184.00	9262.00	9756.0	11118.0	6785.00

Pond and Maner (1974) quoting unpublished data have documented that 40% to 60% of the total nitrogen in cassava is in the form of non-protein-nitrogen (NPN), and the percentage of nitrogen and NPN is higher in peel than in pulp. From Table 2.8 it is apparent that, despite the slight variations, cassava is generally very poor in essential amino acids when compared to cereal grains.

2.4.3 Lipids

Cassava is poor in lipids, leading to deficiency problems in certain animal diets. From Table 2.7, the range is 0.3 to 1.2% ether extract. Most animals require 1 - 2% lipids in their diets (FAO, 1970). Thus, the low lipid content, together with the possibility of being limiting in some essential fatty acids vital for normal body function, renders cassava deficient in lipids. Raymond et al. (1974) recommended that for practical purposes cassava should be considered as containing no lipids.

2.4.4 Minerals and vitamins

Although cassava contains very small amounts of minerals there is great variation due to different soil types and processing methods. Raymond et al. (1974), working with 100 Tanzanian varieties, obtained the following figures: calcium 0.1% and phosphorus 0.2%. Tables 2.6 and 2.7 display a range of 0.04 to 0.24% calcium and 0.04 to 0.12% phosphorus. Pond and Maner (1974) have documented values of 0.12% and 0.16% for calcium and phosphorus, respectively.

The low contents of minerals and vitamins have been observed by many other workers (Magoon, 1972; Maust et al., 1972 ; Hutagalung et al., 1973; Ravoof et al., 1977). However, Hutagalung et al. (1973) noted that cassava contains nutritionally significant amounts of calcium, ascorbic acid, thiamine, riboflavin and niacin.

In spite of the considerable variation, the figures on chemical composition consistently show that cassava is low in dry matter, protein, fat and minerals contents, but the dry matter is rich in energy due to a high content of starch.

2.5 Problems of cassava as a pig feed

Scientific work on the possibilities of replacing cereals by cassava in pig diets began as far back as 1903 (Tracey, 1903). This work was continued by other workers until the second world war (Mondenodo, 1928; Fullerton, 1929; Howie, 1930; Leite, 1939; Kock and Ribeiro, 1942). Subsequently, cassava has been included in pig diets in the tropics and, recently, in the EEC countries due to encouraging results obtained (Oyenuga, 1955; Zarate, 1956, Oyenuga and Opeke, 1957; Oyenuga and Opeke, 1957' Oyenuga, 1961; Modebe, 1963' Maner et al., 1967 Maust et al., 1969; Tillon and Serres, 1973 ; Gomez, 1977, 1979; Sonaiya et al., 1982; Gomez et al., 1983; Oke, 1984; Walker, 1985). It was generally recommended that cassava should replace up to 20 - 40% of the more expensive cereals. There has been a remarkable variation in pig performance. In some experiments, even low levels of inclusion have depressed performance (Velloso et al., 1967; Maust et al., 1969). On the other hand, Chou et al. (1973)

demonstrated that replacement of maize by cassava is possible at levels of up to 60 - 75%. These and many other controversial results are largely due to differences in variety, processing, protein supplements and general diet composition. Some of the reasons for poor performance of pigs fed cassava are discussed below.

2.5.1 Low nutritive value

Cassava is low in protein (Devendra, 1977; Gomez, 1977; Jalaludin, 1977; Khajarern et al., 1977; Ravoof et al., 1977), and programmes based on high levels of cassava therefore require considerably higher protein supplementation than conventional energy sources (Gomez, 1977). The use of cassava is, therefore, heavily dependent on the price and nutritive value of protein sources (Khajarern et al., 1977). Lysine, methionine and tryptophan are especially low, and completely absent in some instances (Jalaludin, 1977). It is generally agreed that methionine, cystine and cysteine (sulphur amino acids) are limiting amino acids in cassava (Khajarern et al., 1977), and this is due to the fact that both cystine and cysteine are involved in cyanide detoxication (Osuntokun et al., 1968).

Cassava root meal is also poor in vitamins and minerals (Oyenuga, 1968; Magoon, 1972; Hutagalung et al., 1973; Jalaludin, 1977; Ravoof et al., 1977) as well as lipids (Raymond et al., 1941; Jalaludin, 1977). It has, therefore, been recommended that additional proteins, vitamins and minerals must be supplemented in cassava - based diets.

2.5.2 Presence of cyanogenic glucosides

The greatest limitation to the use of cassava for livestock feeds is its content of cyanogenic glucosides, linamarin and lotaustralin (Magoon, 1972; Maust et al., 1972; Khajarern et al., 1977). Linamarin (α -hydroxy-isobutyronitrile- β -glucoside) accounts for 93% of the total cyanogenic glucosides and lotaustralin for 7% (Nartey, 1968). Linamarin is synthesized from the amino acid valine, while lotaustralin is produced from the amino acid isoleucine (Onwueme, 1978). Both glucosides are highly soluble in water, and they disintegrate or decompose when heated above 150^{o}C (Onwueme, 1978). These glucosides are catalytically hydrolysed by linase (linamarase) or by the action of organic acids to yield HCN, acetone and glucose (Oke, 1968; Coursey, 1973). Butler et al. (1973) reported that enzymatic hydrolysis of cyanogens takes place when tissues of cyanophoric plants are crushed or autolysed, thereby yielding the sugar moiety and aglycone. Toxicity of cassava is caused by hydrocyanic acid (HCN).

The degree of toxicity depends on variety, ecological conditions for growth of the plant, part of the plant used and the technology of processing (Coursey, 1973). Nartey (1978) stated that although cyanogenesis is genetically determined, it is influenced by various ex-and intrinsic factors, such as soil moisture, climate, rates of synthesis, transport and degradation of cyanogenic materials. According to Bolhuis (1954), the hydrocyanic acid content is greatly influenced by the environmental conditions, particularly dryness and potash deficiency. Cassava grown in wet regions has a higher HCN content than that grown in more dry regions (Onwueme, 1978). It has also been shown that plants growing in soils low in potassium or high in nitrogen contained high HCN concentrations in their tubers. Drought increased glucoside contents, while shading reduced contents in roots (de Bruijn, 1973) and low temperatures favour cyanogenic lines (Daday, 1954).

It has been shown by many workers that HCN both in free and glucoside form exists in variable amounts in both tubers and leaves (Johnson and Raymond, 1965; Gondwe, 1974; Devendra, 1977; Montaldo, 1977). As reviewed by Oke (1978), normal cyanogen contents range from 75 to 350 ppm. Devendra (1977) found a range of 90 - 100 ppm and 180 - 240 ppm for sweet and bitter varieties, respectively. Muller et al. (1975) observed that the contents in fresh tubers vary from 100 - 400 ppm, with bitter varieties containing 200 - 300 ppm and the sweet ones having less than 100 ppm. Marcano (1965) has reported values of 167 - 260 ppm from Venezuelan varieties, while Gondwe (1974) reported values of 45 to 950 ppm in some East African varieties. Analyses of 100 varieties in Tanzania showed contents of HCN of 16 to 434 ppm (Raymond et al., 1941) with an average of 158 ppm. As documented by CIAT (1978), variations between roots of the same variety are considerable. According to Coursey (1973), the concentration of cyanogenic glucosides in most sweet varieties is very substantially higher in the peel than in the flesh, the ratio being 5:1 or 10:1. It is documented by CIAT (1978) that the total cyanide in cassava peels is about 15 to 20 times higher than contents in the parenchyma (pulp) in sweet varieties and about twice that in bitter varieties.

Varieties or cultivars of cassava are classified as 'sweet' or 'bitter' according to their taste. Some of the sweet varieties can be eaten raw. Although the classification is implied to indicate the level of cyanide in the roots, a correlation between 'bitterness' and 'sweetness' does not always exist (Bolhuis, 1954; Gondwe, 1974). The variety C 7566 is known to be very bitter and the variety Mbarika is intermediate, and yet the tubers of the former yielded only one fifth the amount of HCN yielded by the latter variety (Table 2.9). Thus, one variety may be consumed in preference to another, purely on the basis of its taste, and yet it may be potentially more toxic. It is possible that there are other factors responsible for taste than glucoside content. Raymond et al. (1941) noted that the so-called bitter roots in Tanzania are only relatively bitter and their cyanogenic glucoside content is much lower than toxic varieties reported elsewhere. The authors concluded that Tanzanian cassava varieties do not contain much cyanogenetic glucoside.

2.5.2.1 Mode of HCN toxicity

The chronic effects of continuous ingestion of sublethal amounts of cyanide are not exactly known (Maner and Gomez, 1973; Montilla, 1977; Omole, 1977). It was suggested that chronic HCN poisoning appears to be due to interference with the metabolism of sulphur amino acids which are extremely low in cassava protein (CIAT, 1972). Oke (1969) has discussed the role of HCN in nutrition. It is discussed that the majority of the symptoms of poisoning can be explained on the basis of the affinity of HCN with the metabolic ions, such as copper and iron. The cyanide combines with the haemoglobin to form

Table 2.9 :Distribution of HCN in different parts of four local varieties of cassava (ppm) (Gondwe, 1974)

Part of plant	Variety			
	Misto (sweet)	Mbarika (intermediate)	4760/22 (bitter)	C 7566 (very bitter)
Bark of tuber	660	608	950	832
Pulp of tuber	45	330	250	64

cyanohaemoglobin, which hinders the absorption and transportation of oxygen. According to Omole (1979), the cyanide has a reversible combination with the copper of cytochrome oxidase. In this way, the enzyme is prevented from its normal function as an enzyme oxidase in energy metabolism. This is a classic example of histotoxic anoxia. These chemical abnormalities cause a neuronal depression in the medullar centres, that causes respiratory problems and death (Pond and Maner, 1974). Thus, HCN is a violent protoplasmic poison.

The symptoms of acute HCN toxicity have been described by Oke (1969) as increased depth and speed of respiration, accelerated pulse, failure to react to stimuli and spasmodic muscular movements. However, the consumption of small quantities of hydrocyanic acid may have serious toxicological, physiological and nutritional effects and may show symptoms of deficiency of methionine, cystine, sulphur, Vitamin B_{12} , iodine and other trace elements (Pond and Maner, 1974).

2.5.2.2 **Toxic levels of hydrocyanic acid**

The lethal dose of HCN seems to vary with species of animals, and the amount consumed, and has not been fully determined. Garner (1967) noted that only animals which eat rapidly die, and an intake of 4 mg/kg body weight can be regarded as lethal if consumed fairly quickly. It was pointed out that ruminants are more susceptible to poisoning by cyanogenetic plants than horses and pigs, since the enzyme concerned in the release of HCN is destroyed by gastric hydrochloric acid. Other workers have reported lethal doses of HCN to be 1.4 mg/kg body weight (Getter and Bain, 1938; Johnson and Raymond, 1965) and 4.5 mg/kg body weight (Butler et al., 1973).

The expression of the toxicity on the basis of HCN content in the cassava may be misleading, as it will depend on the amount of cassava consumed. Yet, most of the workers have expressed it this way. For acute toxicity, Alvarez-Luna (1972) and a review by Coursey(1973) gave the following guide:

Innocuous:	Less than 50 ppm in fresh peeled tuber.
Moderately poisonous:	50 - 100 ppm in fresh peeled tuber.
Dangerously poisonous:	Over 100 ppm in fresh peeled tuber.

However, the Indian Standards has set a limit of 300 ppm in dry cassava for livestock (Coursey, 1973), while the Council of the European Economic Communities has set the maximum level at 100 ppm HCN (Ingram, 1975). Further, Ikediobi et al. (1980) have documented that cassava containing 144 to 164 ppm HCN after processing is used for livestock in Nigeria. Booth et al. (1976) fed pigs cassava flour from bitter varieties containing 250 - 350 ppm HCN for 28 days without ill-effects. Oyenuga (1961) reported levels of HCN of 340 to 1121 ppm in six varieties toxic to livestock. It seems that the question of lethal doses in animals and toxic levels in cassava has not been resolved. Nevertheless, it would appear more precise to express values as concentrations of HCN in the animal body.

2.5.3 Low palatability and physical form

The powdery nature of cassava meal reduces its palatability (Maner et al., 1967; Chou et al., 1973; Muller et al.,1975; Hew, 1977; Khajarern and Khajarern, 1977; Balogun and Fetuga, 1984), while fresh bitter varieties are not palatable at all (Gomez, 1979). Hew (1977) attributed the decrease in feed intake, when cassava levels were increased, to the powdery nature of the feed causing irritation and reducing palatability. Similar reasons were advanced by Khajarern and Khajarern (1977), Khajarern et al. (1977), Oke (1978) and Castillo (1980). Cassava diets have been reported to cause ulcerogenic effects upon gastric mucosa and irritation to the eyes and respiratory organs (Muller et al., 1975).

2.5.4 **Perishability**

Fresh cassava tubers are very susceptible to deterioration after harvest. Physiological changes begin within 24 hours after harvest (Booth et al., 1976). Microbial changes take place later. The rapid deterioration, which normally occurs within days of harvesting cassava roots, reduces their acceptability for animal feed. This deterioration involves decay or a dark bluish or brownish discolouration, dark or vascular streaking (caused by accumulation of scopoletin) or softening of injured areas. The discolouration and softening are the results of physiological and pathological factors (Montaldo, 1973). Secondary deterioration is due to pathological rots, fermentation, softening of the roots, which occur at a later stage (Booth, 1974).

Owing to the fast deterioration, cassava has to be processed immediately after harvest to avoid losses. The cheapest way of overcoming the deterioration problem is to leave the plants in the ground until the roots are needed. But the soil is very hard during the dry season, and easy harvesting is only possible during the wet. Cassava tubers can be preserved by reburial in the soil after harvest, coating in mud, or simple sundrying after peeling (Booth, 1974). The method of sundrying is the most common one in that it is practical and cheap.

2.6 Methods of improving utilization of cassava and cassava-based diets

2.6.1 Detoxification

Presence of HCN presents a problem to cassava utilization. Detoxification can be achieved by boiling and roasting (Raymond et al., 1941), chopping and drying (Gomez, 1977), foliar application of urea to cassava plants (Sinha et al., 1970), soaking or fermentation (Jalaludin, 1977; Rajaguru et al., 1978), peeling (Ravindran et al., 1983b) and addition of methionine (Maner and Gomez, 1973; Adegbola, 1977).

Tillon and Serres (1973) found that diets based on cassava, either chopped and boiled for one hour, or sliced and dried in the sun, were equally palatable, and digestibility of dry matter was the same. Raymond et al. (1941) and Gondwe (1974) have shown that after boiling, the HCN concentration was reduced to less than 50 ppm, which is safe to ingest. Coursey (1973) in a review concluded that the traditional detoxification methods such as boiling, stewing, roasting, baking, frying, soaking, and fermenting are, generally, very effective.

2.6.1.1 Peeling and drying

After harvesting, cassava tubers can be dried in the sun after peeling. Peeling removes most of cyanide in sweet varieties, because the glucosides are concentrated in the peel (Johnson and Raymond, 1965; Coursey, 1973). The peeled tuber is usually split into two parts or chopped into several pieces and dried.

Chopping of the tubers initiates the action of the enzyme linamarase on the hydrolysis of glucoside, resulting in HCN liberation (Gomez, 1977). The HCN produced vapourises during sundrying. Simple drying of sliced roots was shown to be capable of removing up to 90% HCN at drying temperatures of 60^{o} C (Charavanapavan, 1944). Gomez (1977) showed that meal produced from bitter varieties of cassava by chopping and drying had relatively low HCN contents (100 - 150 ppm HCN on a dry matter basis).

2.6.1.2 **Water soaking and fermentation**

In the fermentation process, the tubers are fermented for two to three days during which period they soften and starch breaks off and separates from the fibrous tissues, so that the glucoside hydrolysis by the catalytic action of linamarase enhances the liberation of HCN, which subsequently dissolves in the water (Coursey, 1973). Thus, soaking and fermenting minimizes the chances of HCN toxicity. According to Coursey (1973), removal or reduction of HCN by either water dissolution or volatilization are achieved by laceration, soaking, boiling, roasting or fermentation of cassava root tubers or a combination of these processes.

2.6.1.3 **Addition of sulphur containing compounds**

Hydrocyanic acid toxicity can be alleviated to a varying extent by organic compounds such as methionine and inorganic compounds such as sodium thiosulphate, which both contain sulphur (Maner, 1972; Maner and Gomez, 1973; Oke, 1973).

Addition of 0.20% methionine improved the performance of weaner pigs fed cassava containing 90 ppm HCN (Hew and Hutagalung, 1972; Hew, 1977). The role of methionine in improving performance was attributed to correction of the methionine deficiency per se, as well as a source of readily available sulphur for cyanide detoxification (Maner and Gomez, 1973). Balogun and Fetuga (1981) demonstrated that addition of 0.8 g DL - methionine/kg diet improved efficiency of feed conversion and growth rate of pigs fed cassava-soyabean meal diets. The improvement in pig performance by addition of methionine to cassava-based diets has been demonstrated by many other workers (Hew and Hutagalung, 1972; Oke, 1973; Maner, and Gomez, 1973; Adegbola, 1977; Sonaiya and Omole, 1983; Balogun and Fetuga, 1984).

Supplementation of cassava diets with 0.1 to 0.2% methionine (Maner and Gomez, 1973) or 0.2% methionine (Creswell et al.,1975) has proved to improve performance of pigs. Hew and Hutagalung (1977) demonstrated that pig performance could be significantly improved by addition of 0.2% methionine. On the other hand, Gomez et al. (1984) failed to obtain response to 0.2 - 0.3% methionine supplementation.

Since animal proteins are rich in methionine, it has been suggested that they should be included in diets high in cyanide. Fishmeal not only supplies methionine but also provides Vitamin B_{12} which serves as an independent pathway for cyanide detoxification

(Oke, 1973). Creswell *et al.* (1975) demonstrated that sodium thiosulphate can donate sulphur for detoxification.

2.6.1.3.1 **Mode of hydrogen cyanide detoxification**

Adegbola (1977) has discussed the role of methionine in the metabolism as a major source of methyl groups in the body. In its active form of S-adenosyl-methionine, the methyl groups can be transferred to guanidoacetic acid to form lecithin and to a number of other substrates to form other products required for various body processes. The residue of these methylation reactions is usually S-adenosyhomocysteine, which is then cleaved to adenosine and homocysteine. Homocysteine breaks down irreversibly in the presence of serine and/or glycine to cystine and cysteine. The final oxidation of these amino acids results in the production of sulphate ions, pyruvate and ammonia (Figure 2.1). Adegbola (1977) suggested that the formation of thiocyanate was the principal route for detoxification of cyanide and that the liver was the chief site of detoxification. The enzyme rhodanese occurs in various body tissues and is responsible for the conversion of the cyanide ions to thiocyanate under aerobic conditions in the presence of thiosulphate colloidal sulphur (Figure 2.1).

$$HCN + Na_2S_2O_3 \longrightarrow HSCN + Na_2SO_3$$

It was concluded that the thiosulphate ion was the only sulphur-containing compound capable of efficiently providing sulphur. It was noted that the reaction of cysteine yields cysteine and B-thiocyanoalanine, which tautomerizes to 2-aminothiazolidine-

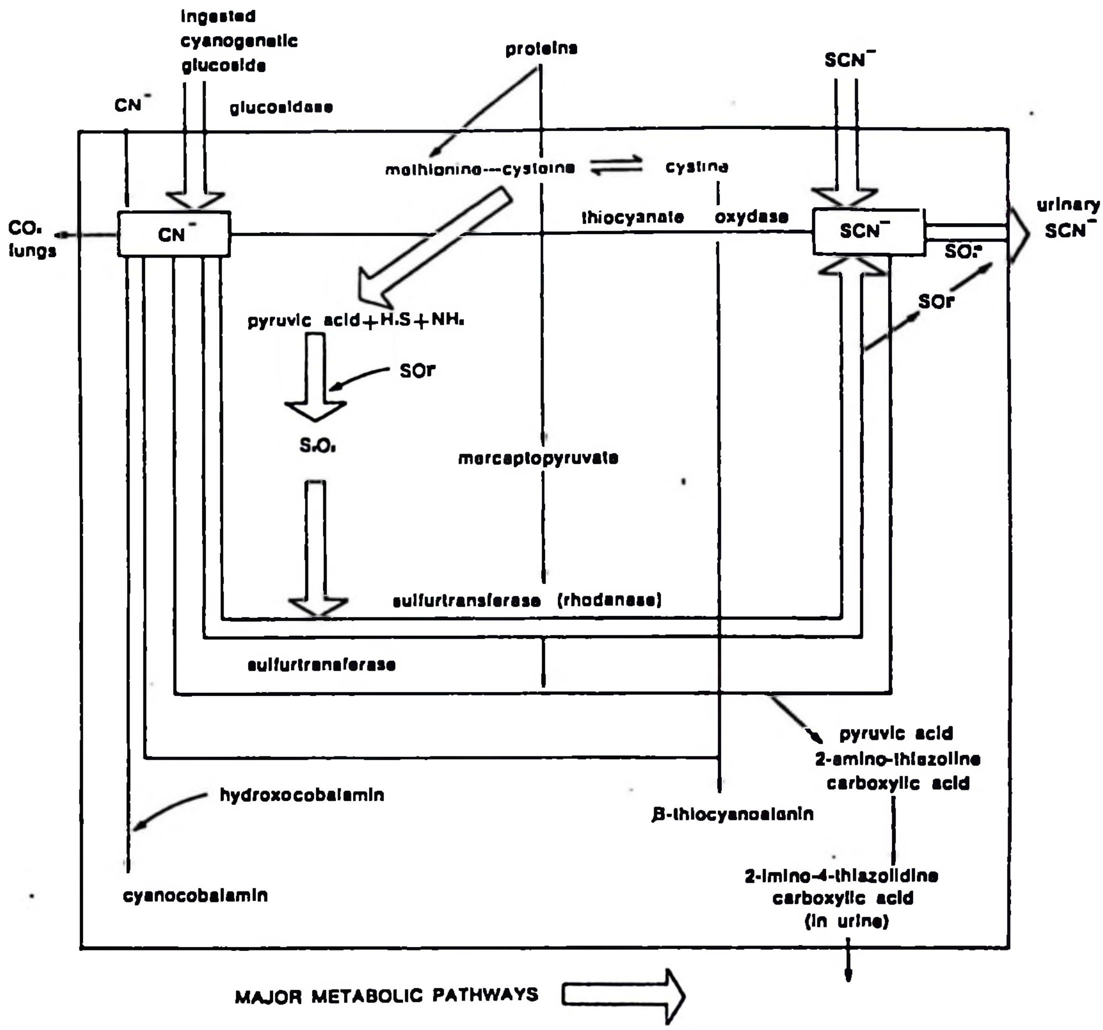


Figure 2.1. Principal metabolic pathways of the cyanogenetic glucosides, cyanide and thiocyanate (Job, 1975).

4-carboxylic acid or the equivalent 2-imino-4thiozolidine carboxylic acid. When cyanide enters the body, 2-imino-4thiazolidine carboxylic acid is excreted in the urine.

Oke (1978) noted that 3 mercaptopyruvic acid arising from cysteine by transamination or deamination can provide sulphur as rapidly as thiosulphate for cyanide detoxification. It was concluded that methionine per se is not the substance required for formation of thiocyanate by rhodanese and that to make methionine sulphur available for detoxification purposes, methionine has to be metabolized. Sodium thiosulphate has been used for the same purpose by various workers (Creswell et al., 1975; Kakala, 1981).

In a review , Oke (1978) pointed out that Vitamin B_{12} , occuring as hydroxocobalamine, can react with cyanide to give cyanocobalamine thus constituting another pathway for cyanide detoxification. Hew and Hutagalung (1972) and Hew (1972) have suggested improved performance of pigs supplemented with glucose to be due to a reduction of HCN by formation of glyconohydrin.

In monogastrics it is known that detoxification takes place also in the stomach through the reaction of dietary HCN and gastric hydrochloric acid (HCl). Oke (1969) discussed the reaction of HCN with HCl to form less toxic acids such as formic acid and ammonium chloride. The process is fast in the pig because of ample supply of HCl (Oke, 1969).

$$HCN + CHl + 2H_2O \longrightarrow HCOOH + NH_4Cl$$

2.6.2 Nutrient fortification

It has been mentioned that cassava is deficient in protein, minerals, vitamins, and fats. Hew and Hutagalung (1972) have shown that methionine fortification in cassava-based diets was necessary because some of the methionine is used as a source of sulphur in detoxification and hence the sulphur amino acids may be depleted and thus become limiting. The role of methionine in improving performance has been attributed to correction of the methionine deficiency per se, as well as being a source of readily available sulphur for detoxification.

Maust et al. (1972) demonstrated that pigs fed cassava-rice bran diets developed parakeratosis and had a poor performance, which was only corrected by zinc supplementation. The authors showed that the cassava-based diets were deficient in zinc thereby depressing digestibility of nutrients. The depression was corrected by addition of 100 ppm $ZnCO_3$.

Fortification of cassava diets with fat (Walker, 1985), iodine (Ermans et al., 1973; Hutagalung, 1977) and Vitamin B_{12} (Oke, 1973) have proved to improve performance of pigs fed cassava, and this has been attributed to deficiency of minerals and vitamins in cassava. Skin lesions, which developed when pigs were fed 45 - 60% cassava, were alleviated following a double dose of vitamins and minerals (Hutagalung, 1972). Addition of calcium and phosphorus to cassava-based diets is important because the availability of these minerals is rendered difficult due to oxalic acid in cassava roots (Raymond et al., 1941).

2.6.3 Improving physical form and palatability

Improvement in pig performance due to addition of glucose and/or palm oil or fishmeal has been attributed partly to improvement in palatability of cassava diets (Hew and Hutagalung, 1972; Hew, 1977; Khajarern et al., 1980c). To reduce the powdery texture of cassava meal, cane sugar molasses was added and this improved pig performance (CIAT, 1972, 1978). Khajarern et al. (1980c) found that fishmeal and cane sugar molasses improved the palatability of cassava-based diets resulting in higher feed consumption and faster growth rate. The problem of the powdery texture can be partially remedied by pelleting the diet (Muller et al., 1975) and by feeding cassava paste (Khajarern et al., 1979). Muller (1977) and Khajarern and Khajarern (1984) have pointed out that pelleting can reduce the volume of cassava by 25 to 40% and thus eliminate the dust. Pelleted cassava gave faster growth and higher efficiency of feed conversion than maize, but there was no difference when cassava was not pelleted (Chou et al., 1973).

2.7 Effects of feeding cassava-based diets to pigs

The results of feeding cassava roots are conflicting due to genetic variations, variations in the types of protein supplements, the physical quality of the rations, method of processing, chemical composition of varieties, locality and method of chemical analysis (Hew, 1977). It has been generally recommended that cassava could replace cereals at the 20 - 40% level (Tillon and Serres, 1972). Much of the work done on cassava as a pig feed has been reviewed by Ravindran et al. (1983b) and Oke (1984).

2.7.1 Effect on feed intake, feed efficiency and growth rate

Inclusion of 35% cassava meal in pig diets in Malaysia produced daily gains and feed/gain ratios of 0.43 kg and 3.01, 0.49 kg and 3.92, and 0.43kg and 5.00 from 20 to 40 kg, 40 to 60 kg and 60 to 84 kg liveweight, respectively (Ong, 1976).

Maner (1973) fed freshly chopped cassava with a protein supplement to appetite or rationed to meet minimum requirements. Average daily gains were 774 g and 730 g/day for pigs reared outdoors and 834 and 794 g/day for pigs reared indoors. Using different protein sources, the author demonstrated that even with a poor quality protein like cottonseed meal, the daily gains were very encouraging at 592 g/day. Gomez et al. (1976) found that fresh bitter cassava roots are not readily consumed by pigs. With a protein supplement supplied ad libitum with chopped fresh bitter roots, the pigs consumed an excess of the supplement to compensate for limited intake of bitter roots. When fed in a mixture, the pigs lost weight, as they consumed insufficient amounts of feed for maintenance requirements. Finishing pigs (20 - 90 kg) fed sweet fresh cassava and a protein supplement ad libitum or restrictedly gained 770 g and 660 g per day, respectively. The feed/gain ratios were 2.99 and 2.61, respectively. In subsequent studies, Gomez (1977) showed that pigs fed fresh cassava roots and protein supplement ad libitum gained 830 g/day, while those fed controlled quantities gained 790 g/day. Restriction of both cassava and the protein supplement resulted in a better feed efficiency.

Boiled and raw cassava tubers have been shown to efficiently replace 42% sorghum in pig diets (Oyenuga, 1961). Boiling did not improve performance at a 42% replacement rate, but it did so at a 55% replacement.

Khajarern et al. (1977) recommended the use of not more than 50% cassava diets for pigs up to 35 kg and 70% for heavier pigs. Wyllie and Lekule (1980) did not observe any significant difference when cassava replaced up to 54% maize in pig diets. However, cassava was superior to molasses at all levels up to a 68% replacement. Gomez and Valdiviesc (1983) observed that cassava-based diets were more palatable than sorghum-based diets for baby pigs. Gomez et al. (1983) showed that cassava diets (from low and high cyanide cultivars) were comparable to sorghum-based diets for growing-finishing pigs.

In a series of experiments, Chou et al. (1973) demonstrated that pigs fed 38% cassava and supplemented with variable amounts of soybean meal, fishmeal, lysine and methionine performed as well as pigs fed maize diets. When the cassava was pelleted and protein and energy reduced while lysine was increased, the cassava diets produced higher growth rates and feed efficiency. It was shown that up to 60% and 75% of cassava can replace maize with satisfactory results. Table 2.10 shows a summary of some of the selected work on the effect of replacing cereals by cassava.

Cassava meal is commonly included in pig experimental diets at the Sokoine University of Agriculture at levels of 20 to 30% (Lekule

Table 2.10 :**Effect of replacing cereals by cassava on growth rate and feed utilization**

Authors	Level of cassava (%)	Growth rate	Feed intake	Feed efficiency
1. Onaghise and Bowland (1977)	< 40	None	None	None
2. Onaghise and Bowland (1977)	> 40	Reduced	Reduced	-
3. Hansen *et al*.(1976)	60	Slightly reduced	-	Slightly reduced
4. Hew and Hutagalung (1972)	10-50	Reduced	-	Reduced
5. Hew and Hutagalung (1977)	60	Reduced	Reduced	Reduced
6. Hutagalung *et al* (1973)	60	Reduced	Reduced	Reduced
7. Manickan and Gopalakrishnan (1978)	20	None	None	None
8. Manickan and Gopalakrishnan (1978)	30	Reduced	-	Reduced
9. Chicco *et al*.(1972)	> 40	Reduced	-	None
10. Velloso *et al*. (1972)	22	Reduced	-	Reduced
11. Maust *et al*.(1972)	36	Reduced	Reduced	-
12. Walker (1985)	71	Reduced	-	None
13. Wyllie and Lekule (1980)	54	None	None	None

et al. , 1982). It can be concluded that majority of the studies reported have shown reduced growth rate and reduced feed efficiency (Table 2.10). However, the economics of cassava utilization was not reported in these studies.

2.7.2 Effect on digestibility and energy utilization

The low fibre content and high energy in cassava makes it a valuable source of feed. Hew and Hutagalung (1976) showed that cassava improves the digestibility of organic matter. 60% cassava diets had a digestibility of 80.59% , whereas a maize control diet had a digestibility of 80.86%. Just *et al.* (1983a) gave a value of 85% as the dry matter digestibility. Pond and Maner (1974) have shown a higher value of 93.8%. The digestibility of cassava has been reported to be comparable to that of maize and other cereals (Maust *et al.*, 1972; Tillon and Serres, 1973).

Muller *et al.* (1975) have reported the energy value of cassava for pigs to be 4.0 Mcal DE/kg and 3.8 Mcal ME/kg. Similar values were reported by other workers (Tillon and Serres, 1973; Khajarern *et al.*, 1977). Olson *et al.* (1969) have reported a value of 3.44 Mcal ME/kg.

Pond and Maner (1974) have quoted the energy values of 3.8 Mcal DE/kg and 3.6 Mcal ME/kg (3.5 Mcal ME/kg adjusted). Aumaitre (1969) determined a digestible energy value of 4.19 Mcal/kg for cassava, while the value for cereals was about 4 Mcal/kg. Just *et al.* (1938a) have documented values of 3.5 Mcal DE/kg dry matter and 3.4 Mcal ME/kg dry matter. Khajarern *et al.* (1977) have pointed out that the energy value of cassava depends on its contents of ash and crude fibre. A DE value of 2.8 Mcal/kg or less was estimated for cassava with more than 5% ash and fibre each, and a value as high as 3.7 Mcal/kg with ash at less than 2.2% and crude fibre at less than 2.8%.

Walker (1983) argued that the use of published DE values for cassava may overestimate its nutritive value, since the utilization of DE and ME may be less efficient with diets containing cassava than cereal-based diets. Since cassava contains a high proportion of amylopectin (Oke, 1978), it has been suggested that this may increase the quantity of undigested carbohydrate reaching the large intestine, thus increasing the substrate for microbial activity (Walker, 1983). Just et al. (1983b) have shown that the ratio of DE to ME falls as the proportion of energy absorbed from the hind gut increases.

2.7.3 **Effect on carcass characteristics**

Most workers have not found any effect of cassava quality in pigs (Chou and Muller, 1972; Muller et al., 1972; Hansen et al., 1976; Hew and Hutaalung, 1977; Wyllie and Lekule, 1980; Sonaiya et al., 1982; Obioha et al., 1985).

However, Oyenuga and Opeke (1957) and Hutagalung et al. (1973) showed that cassava-fed pigs accumulated more fat than cereal fed pigs. Babyegeya (1980) observed decreased backfat thickness and increased killing out percentage as the level of cassava increased in the diet.

2.7.4 Effect on reproductive performance

There is limited literature on the effect of feeding cassava to breeding pigs. The long-term effects are not exactly known. The appearance of splay legs in piglets farrowed by sows fed 30% cassava was postulated to becaused by low crude fat and, hence, a deficiency of choline and an imbalance due to methionine deficiency (Hew, 1977). Whereas this author found no effect of cassava level on litter size and litter weight, Gomez et al. (1976) demonstrated that high levels of cassava meal produced smaller litters. Later, in an intensive study, Gomez (1979) found that litter size and birth weight were similar for gilts fed cassava and those fed maize, but the cassava diets failed to support the lactation requirements thereby resulting in a high rate of mortality among piglets.

2.7.5 Effect on health

A poorly balanced diet with cassava can result in skin lesions (Hew and Hutagalung, 1972; Maust et al., 1972) and posterior paralysis (Oyenuga and Opeke, 1957). Weaners developed diarrhoea (Hutagalung, 1972; Maust et al., 1972; Arambawela et al., 1975; Hansen et al., 1976). The skin lesions (parakeratosis) were alleviated by a double dose of vitamins and minerals, while diarrhoea disappeared after a period of adaptation or by restricted feeding. Aumaitre (1967), on the other hand, observed a higher frequency of diarrhoea for barley, wheat, maize and oats diets than for cassava-based diets. There is some evidence that cyanide may induce digestive disturbances (Maner et al., 1967; Rajaguru et al., 1978).

Acute poisoning as a result of cassava consumption by man or domestic animals is not particularly common but is by no means unknown (Coursey, 1973). Nartey (1978) stated that, in human nutrition, prolonged consumption of cassava or its products may lead to cyanide intoxication, which is correlated with a high incidence of goitre, tropic neuropathy, cretinism and deficiencies in sulphur amino acids and in Vitamin B_{12} in the peoples of Africa, Asia, the West Indies and South America. Sihombing et al. (1974) and Cromwell et al. (1975) found that inclusion of goitrogenic substances in pig diets resulted in growth depression, hypothyroidism, skeletal malformation, laboured respiration, and lethargy. Ekpechi et al. (1966) observed that cassava depleted the iodine stores of the thyroid gland and also impaired the transfer of 3-monoiodotyrosine to 3, 5-diodotyrosine in the gland. Iodine uptake is energy-dependent and is inhibited by cyanide (Hutagalung and Tan, 1976). Cyanide detoxification produces thiocyanate, which exerts a goitrogenic effect on the body that can cause thyroid hypertrophy, especially in the absence of adequate dietary iodine (Sihombing et al., 1974; Cromwell et al., 1975).

2.8 Effect of sex and plane of nutrition on pig performance

Passback et al.(1968) found that restricting feed intake of pigs decreased average daily gain and dressing percentage, tended to decrease backfat thickness and to increase the loin eye area but had no effect on carcass grade. Restriction of feed intake has been reported to lead to decreased fat in pork carcasses (Fuller and

Livingstone, 1978). Improvement in efficiency of feed conversion by feed restriction has been reported by Merkel et al. (1958).

Hale and Southwell(1967) have shown that barrows gain faster than gilts, produce shorter carcasses, have a lower dressing percentage, had a higher backfat thickness figure but a similar feed conversion efficiency.

In a restricted feeding experiment, Lekule et al. (1982) observed that barrows gained faster, had a higher efficiency of gain and more backfat than gilts. Similar results were obtained by Bruner and Swiger (1968) and McKinnon and Bowland (1977). Castell et al. (1985) have also found that castrates grow faster than gilts, but the efficiency of feed conversion was the same when pigs were self-fed. The observations are contradictory to those of Fuller and Livingstone (1978) who showed that at high intakes there was no difference in growth rate between castrates and gilts, but with progressive feed restriction, the growth of males (castrates) was more severely retarded than that of gilts. These authors concluded that energy requirements for maintenance were 15% greater in males than in females.

CHAPTER 3

MATERIALS AND METHODS

3.1 General

3.1.1 Feeds and feed formulation

Feedstuffs were obtained from several sources, viz rice polishings from Dakawa Rice Farms, oilcakes from The Multipurpose Oil Processing Company (MOPROCO), dried cassava chips and maize from N.M.C., Dar es Salaam, sow and weaner meal, premix and part of the local fishmeal from the Tanzania Animal Feeds Company (TAFCO), and limestone from Dar Lime Company. The rest of the fishmeal was prepared by milling the 'local fish 'dagaa' (Limnothrissa spp and Stolothrissa spp.) bought from the market. The fish originated from Lake Victoria and Lake Tanganyika. The fresh cassava was obtained from nearby farmers. The feedstuffs were ground through a hammer mill.

Samples of the feedstuffs were collected and analysed. Diets were formulated, and mixing was done once per week. Samples of the diets were taken and bulked. The feedstuffs and diets were analysed for contents of dry matter (DM), crude protein (CP), crude fibre (CF), crude fat (EE), ash, calcium (Ca) and phosphorus (P) in accordance with AOAC (1980). Amino acid analyses were made on the feedstuffs in accordance with the procedures of Mason et al. (1980).

3.1.2 Routine operations and care in growth experiments

All the pigs were crossbreds of Large White and Landrace and identified by earnotching. The male pigs were castrated at 3 weeks of age. The animals were dewormed and treated against mange prior to each experimental period, and these treatments were carried out routinely throughout the experiments.

The animals were randomly allocated to treatments on a within-litter/sex basis, so that each treatment lot was balanced for sex, weight and, as far as possible, litter. These pigs were offspring of four sows kept at the Departmental Pig Research Unit, Sokoine University of Agriculture. The treatment lots were then randomly allocated to pens in completely randomized design.

The animals were housed in concrete pens and had a preliminary period of 7 days. They were fed twice per day at 8 a.m. and 3 p.m. The diets were given as dry mash. Water was offered *ad libitum.*

The experimental pigs were weighed once per week. As they approached 90 kg liveweight, they were weighed more frequently and slaughtered as near to 90kg lwt as possible, i.e. when there was a possibility of selling the carcass (usually on Wednesdays and Saturdays). In the case of restrictedly fed pigs, they were not given food on the slaughter day because they were slaughtered before their feeding time.

3.1.3 Statistical analysis

The data in all the experiments were subjected to analysis of variance (SAS, 1982).

The analysis of variance model (general linear model) was:

$$X_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

where:

i	= number of treatments
j	= number of sexes
α_i	= effect of ith treatment
β_j	= effect of jth sex
μ	= mean (location parameter common to all observations)
$(\alpha\beta)_{ij}$	= interaction between the ith diet and jth sex
ε_{ijk}	= error term with mean zero and variance

3.2 Experiment 1: Effect of substituting maize for cassava root meal on performance of growing-finishing pigs

24 pigs were allocated to four dietary treatments. The initial weight (after the preliminary period) was 34 kg (17 to 41.5 kg) on average and completely randomized design was used.

Cassava root meal replaced maize meal at the rate of 0, 15, 30 and 45% for a period of 28 days (period 1). The levels of cassava were then increased to 0, 20, 40 and 60%, while those of maize meal were maintained constant (period 2) (Table 3.1). During this period all the diet ingredients were changed by getting rid of cashewnut cake and reducing the levels of kapok cake, which were suspected to be the cause of poor performance observed during period 1.

The animals were housed in two pens of 12 sq. m. each and fed individually in 12 separate feeding stalls, outside the pens,

Table 3.1 : Diet composition for experiment 1. In percent

Ingredient	Treatment			
	A_1	B_1	C_1	D_1
Period 1				
Cassava root meal (CRM)	0	15	30	45
Maize meal	45	30	15	0
Cottonseed cake	10	15	20	25
Cashewnut cake	22	17	12	7
Kapok cake	19	14	9	4
Soyabeans (pre-cooked)	0	5	10	15
Fishmeal	2.5	2.5	2.5	2.5
Limestone	1.0	1.0	1.0	1.0
Premix[1)]	0.5	0.5	0.5	0.5
Period 2				
Cassava root meal	0	20	40	60
Maize meal	45	30	15	0
Cottonseed cake	10	15	20	25
Rice polishings	30	25	15	0
Kapok cake	11	6	6	11
Fishmeal	2.5	2.5	2.5	2.5
Limestone	1.0	1.0	1.0	1.0
Premix[1)]	0.5	0.5	0.5	0.5

1) Contents per gram Premix.

Vit. A 2,500 I.U.	Vit. B_2 1.0 mg	Vit. B_{12} 0.005 mg
Vit. D_3 400 I.U.	Vit. B_6 0.5 mg	D-pantothen-
Vit. E 2.0 mg	Vit. PP 0.5 mg	ic acid 2.5 mg
Cobalt (Co) 0.06 mg	Iron (Fe) 9.0 mg	Menadione so-
Iodine (I) 0.3 mg	Manganese	dium bisulphite
Vit. B_1 0.5 mg	(Mn) 16.0 mg	(Vit. K_3) 0.5 mg
Choline	DL-methi-	Copper (Cu) 4.0 mg
Chloride 200 mg	onine 20.0 mg	

according to a local feeding standard (Table 3.2). The diets were formulated to be as isonitrogenous and as isocaloric as possible. The pigs were fed twice a day at 8 a.m. and 3 p.m., respectively, and refusals were collected daily.

On reaching 90 kg, the animal was sent to the slaughter-house. It was rendered insensitive by striking it on the forehead with a steel bar. It was immediately bled by cutting its throat and severing off the head, which was detached at the atlas joint and weighed. The thyroid gland was removed and weighed in the laboratory. Dehairing of the carcass was the next step, followed by suspension of the carcass by sticking gambrel sticks into incisions made in the gammcords. Viscera were removed and the carcass halved.

The two sides were weighed. Kidney and kidney fat were separated from the left side of the carcass, from which all carcass measurements were also taken on the hot carcass while suspended. The carcass length was recorded from the anterior edge of the aitch bone (Os pubis) to the atlas. Backfat thickness was measured at five points, viz. at the thickest area near the first rib (Shoulder), at the thinnest area near the last rib (loin), and at the anterior, mid-and posterior end of M. gluteus medium (lumbar). (Plate 1). The empty body weight-E (EBWE) was calculated as the weight of the carcass including the head but after removal of entrails.

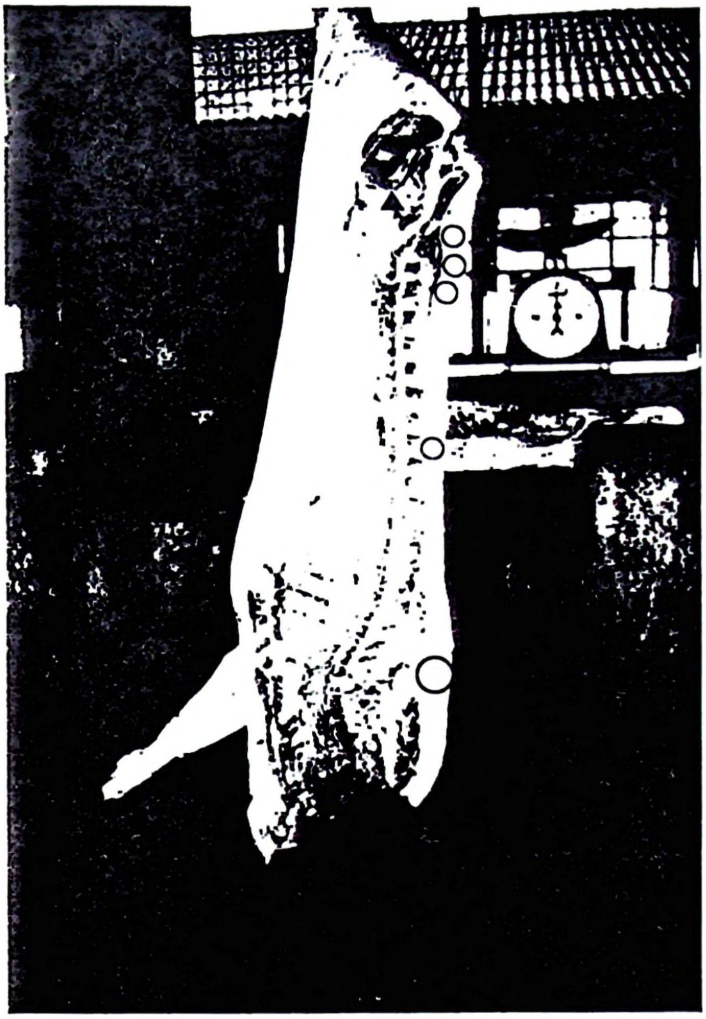


Plate 1. Measurement of carcass length and backfat thickness.

3.3 Experiment 2 : Digestibility of diets based on maize and cassava root meal

Two castrated male pigs from the same litter were put into two steel metabolism cages (Plates 2 and 3). The pigs weighed 28.0 and 30.0 kg initially. They were fed the diets used in experiment 1 (Table 3.1, period 2). The animals were fed twice a day at 8.00 a.m. and 3.00 p.m. The diets were fed in rotation over four periods so that each pig was fed the same diet in two different periods. The amount of feed increased through 1.0, 1.4, 1.6 and 1.8 kg for the four periods (Table 3.3). Water was offered at the rate of 2.5 kg/kg feed. A collection period of seven days was preceded by a preliminary period of five days. The animals were weighed before and after the experimental period. Rations for 12 days (preliminary + collection period) were weighed out as one batch.

3.3.1 Collection of faeces and urine

Faeces were collected twice a day, while urine was collected once a day. Both urine and faeces were weighed once a day. The 3.00 p.m. faecal collection was mixed with the faecal collection the following morning at 8.00 a.m. All collection containers were pre-weighed and permanently labelled before the start of the experiment.

Faeces was collected and weighed in 4 litre plastic containers and emptied into 15 litre plastic buckets stored in a deep freezer at -20 ^{o}C. Urine was collected in 6 litre plastic containers containing 20 ml of 0.3M copper sulphate in 4N sulphuric acid, in

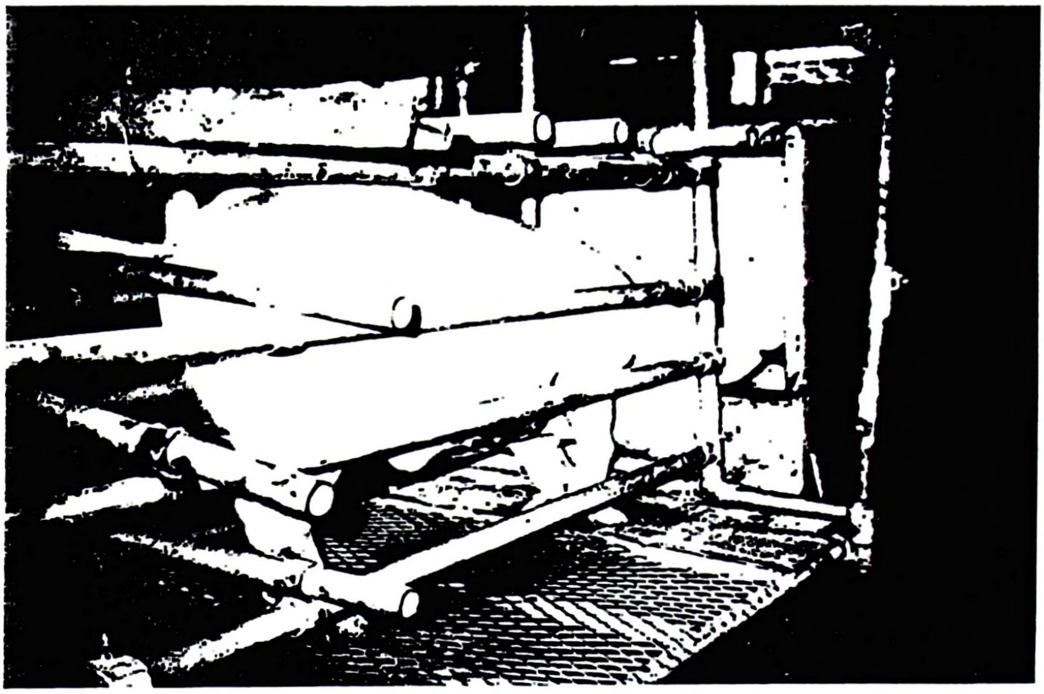


Plate 2. A castrate pig in a steel metabolism cage.

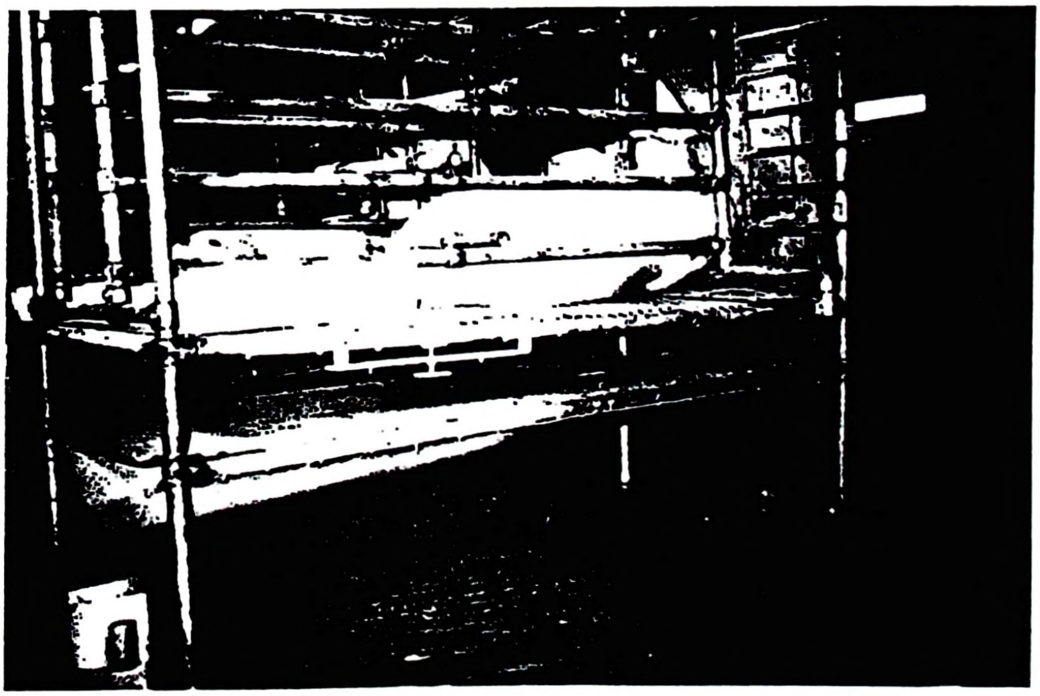


Plate 3. A set-up for collection of faeces and urine.

Table 3.3 :Treatments and feeding arrangements for experiment 2

	Periods 1		2		3		4	
	Sub periods							
	I	II	I	II	I	II	I	II
	Treatments							
Pig No. 57	B_1	D_1	A_1	C_1	B_1	D_1	A_1	C_1
Pig No. 53	A_1	C_1	B_1	D_1	A_1	C_1	B_1	D_1
Feed, kg/pig/day	1.0	1.0	1.4	1.4	1.6	1.6	1.8	1.8
Water/kg/pig/day	2.5	2.5	3.5	3.5	4.0	4.0	4.5	4.5

order to prevent loss of nitrogen. Urine was weighed in 6 litre containers and 10% sampled into 3 litre containers and kept at +4^{o}C in a refrigerator. At the end of the collection period, the last collections were stopped at exactly the same time as the first day collections were started.

3.3.2 **Sampling of faeces and urine**

The buckets containing faeces were thawed and weighed. Weight was counterchecked with the daily collections (to ensure that the differences did not exceed 100 g), and this was taken as the total weight of faeces. A weighed amount of water was added to each bucket of faeces to make mixing easy and thorough. Two samples were collected from each bucket. One of the samples was kept in an airtight bottle and frozen for nitrogen determination. The rest of the faeces, or part thereof, formed the second sample. This was weighed into a pre-weighed tray and dried in an oven for determination of dry matter, crude fibre, ether extract and ash. These fractions were later determined by procedures outlined by AOAC (1980).

Samples of urine were thoroughly mixed and sub-sampled into bottles for determination of nitrogen content.

Metabolizable energy content was calculated in accordance with Andresen and Just (1982).

$$ME,\ KJ/kg\ DM = 21.3x_1 + 37.7x_2 + 17.2x_3 + 17.2x_4$$

where:

x_1 = g dig. protein per kg DM

x_2 = g dig. fat per kg DM

x_3 = g dig. crude fibre per kg DM

x_4 = g dig. NFE per kg DM

3.4 Experiment 3 : A comparison of cassava and other energy sources for growing-finishing pigs

Twenty four pigs with an average weight of 33 kg (24 to 42 kg) were allocated to four dietary treatments in a completely randomized design. The treatments were : A_1 - sow and weaner meal (commercial feed based on maize and sorghum), B_2 - cassava root meal diet, C_2- raw cassava diet (soaked cassava + protein concentrate) and D_2 - rice polishings diet (Table 3.4).

The animals were initially housed in four pens, each measuring 3 x 3 m and with two troughs - one for feed and one for water. The pen housing pigs on treatment C_2 had three troughs. The animals were group fed the four diets ad libitum. The protein supplement was initially fed ad libitum, but due to a tendency to excess consumption, concentrate was limited to 1 kg initially and later increased to 1.5 kg/pig/day. The pigs were moved to larger pens (3.2 x 3.8 m) giving a space allowance of 2 sq. m per pig. Each pen had a water trough of 1.5 m in length and a feeding trough of 1.6 m. During this period the protein concentrate (C_2) was offered first, and when cleared, cassava tubers were offered ad libitum.

Table 3.4 : Diet composition for experiment 3. In percent

Ingredient	Treatment			
	A_2 control	B_2 CRM	C_2^1 CRT	D_2 Rice Pol.
Cassava root meal (CRM)	Sow and weaner meal	60.00	0	0
Cottonseed cake		35.50	86.75	15.0
Rice polishings		0	0	79.5
Fishmeal		2.50	6.25	2.5
Limestone		1.50	4.50	2.0
Salt		0.50	1.25	0.5
Premix[2]		0.50	1.25	0.5
Total	100	100	100	100
Ferrous sulphate monohydrate ($FeSO_4.H_2O$), g	0	125	350	75

1 = C_2 is a protein mixture fed with raw, peeled soaked cassava

2 = Same as used in experiment 1

A_2 - contained 40% sorghum, 25% maize, 10% cottonseed cake, 25% sunflower cake and 3.5% fishmeal.

Fresh cassava was purchased from nearby farms. The varieties involved were all sweet viz. Kigoma, Mzungu, Msenene and Ndunga. The tubers were harvested, washed, peeled and soaked in static water for at least 24 hours. Before being fed, the tubers were chopped. The daily feed intake was closely monitored so that no refusals were collected. Each day's feed offered was determined by the feed consumption the previous day.

The same slaughter procedure and carcass measurements as in experiment 1 were followed. In addition, weight of kidney, heart, spleen and liver were recorded. The gastrointestinal tract (GIT), small intestine (SINT) and large intestine (LINT) were weighed with contents (F) and empty (E). The lengths of the small intestine (SINTL) and large intestine (LINTL) were also recorded. The gut measurements were taken after removing the urino-genital organs.

3.5 Experiment 4 : **Digestibility of diets based on cassava and other energy sources**

Four male castrated pigs were put into four metabolism cages. Two of these cages had wooden frames but steel floors, while the other two were all steel. The initial weights of the pigs were 28.0, 28.5, 30.5 and 32.0 kg. The diets used in experiment 3 formed the respective treatments. The animals were randomly allocated to treatments in a 4 x 4 Latin square design. The amount of feed offered was constant throughout the four experimental periods (Table 3.5). The best ratio of water:feed was found to be 1.5:1, and this was adopted during feeding. However, extra water was offered later

Table 3.5 : Treatment and feeding regime for experiment 4

	Periods			
	1	2	3	4
Pig No.	Treatment			
75	D_2	C_2	B_2	A_2
77	A_2	D_2	C_2	B_2
106	C_2	B_2	A_2	D_2
112	B_2	A_2	D_2	C_2
	A_2	B_2	C_2	D_2
Feed, g/ pig/day	800	800	400 prot. 1200 CRT	800
Water,g/ pig/day	2000	2000	1200	2000

to bring the ratio to 2.5:1. The low ratio of water:feed (1.5:1) is probably the result of dry mash feed being the normal feeding regime. The rest of the feeding procedure, faeces and urine collection, sampling and analyses were as for experiment 2.

3.6 Experiment 5 : **Cottonseed cake and sunflower cake as sources of protein in cassava based diets for growing-finishing pigs.**

Twelve pigs weighing 19 kg (12 - 27 kg) were allocated to three dietary treatments by sex, weight, and litter. Cottonseed cake (CSC) and sunflower cake (SC) formed the main protein sources and were compared without addition of detoxicants (Table 3.6). The cassava used in this experiment was harvested on nearby farms. Although the objective was to feed fresh cassava unpeeled in treatment A , the pigs consistently peeled the tubers, which were chopped before feeding. The peels were collected as refusals. It was decided to peel the cassava before chopping and feeding. The fresh cassava tubers were stored in a cold room at $4^{o}C$ and were peeled and weighed during feeding. For treatment B_3 and C_3 , the tubers were peeled, chopped and dried in a barn for several days immediately after harvest. The chips were then milled. In treatment A_3, the protein concentrate was fed at the rate of 1 kg/pig/day throughout the experiment, while cassava was offered _ad libitum_.

The pigs were housed in three pens of 3 x 3 m each with several troughs and waterers. The cafeteria system was used in Treatment A_3.

Table 3.6 : Diet composition for experiment 5. In percent

Ingredient	Treatment		
	Protein conc. for A_3	B_3 CRM + CSC	C_3 CRM + CSC + SC
Cassava root meal (CRM)	0	55.0	55.00
Cottonseed cake	47.0	40.4	20.40
Sunflower cake	41.5	0	20.00
Fishmeal	6.25	2.50	2.50
Limestone	4.50	1.50	1.50
Salt	1.50	0.50	0.50
Premix[1]	0.25	0.10	0.10

1 - Contents per g Premix:

Vit. A	10,000 I.U.	Fe	80 mg
Vit. D_3	1,000 I.U.	Zn	45 mg
Vit. E	10 mg	Cu	6 mg
Mg	100 mg	I	2 mg
Mn	50 mg	Co	0.8 mg

The same feeding, slaughter and carcass evaluation procedures as in experiment 3 were followed. The killing out percentage was calculated as the weight of the carcass after removing the gastrointestinal tract, internal organs, head and trotters.

3.7 Experiment 6: Effect of plane of nutrition and sex on performance of growing-finishing pigs fed a standard cassava diet

Twenty four pigs consisting of 12 barrows and 12 gilts were used in a 2 x 2 factorial experiment. The barrows were allocated to two treatments by ensuring that they were balanced for weight and litter. The gilts were similarly allocated to two treatment lots. This constituted four treatment lots, as shown in Table 3.7. Group feeding was used. The animals were housed in pens measuring 3.2 x 3.8 m and they had an initial weight of 24 kg (16 to 38 kg). Water was allowed to run through at a corner of the pen. All the pigs were fed a cassava diet which was considered a standard diet under Tanzanian conditions (Table 3.8).

The feeding scale in experiment 1 (Table 3.2) was used for treatment lots C_4 and D_4. Feeding, slaughter and carcass evaluation procedures used in experiment 5 were followed.

Table 3.7 : **Experimental design for experiment 6**

Ad libitum		Restricted	
Barrows	Gilts	Barrows	Gilts
A_4	B_4	C_4	D_4

Table 3.8 : **Composition of diet in experiment 6**

Ingredient	Percentage
Cassava root meal	59.95
Cottonseed cake	36.00
Fishmeal	2.50
Salt	0.50
Premix[1)]	0.50
Limestone	0.40
$FeSO_4.H_2O$	0.15
	100.00

1) Same Premix as in experiment 5.

CHAPTER 4

RESULTS

4.1 Chemical composition of cassava

The chemical composition of various Tanzanian cassava varieties is shown in Tables 4.1 and 4.2. Cassava used in the present study was peeled, and the peels formed about 20% of the fresh weight of cassava roots. The peeled roots had a dry matter content of about 35%. Cassava harvested during the dry season had a higher dry matter content. Contents of crude protein, crude fibre, ether extract and ash were approximately 2.0, 3.5, 0.6 and 2.5%, respectively. The NFE content was 91%. Contents of ash were slightly higher in the unpeeled roots, while the NFE content was slightly lower than in peeled roots. Peels, on the other hand, had higher nitrogen, crude fibre (NDF) and ash contents and a much lower starch content than whole roots.

Contents of amino acids in cassava roots are very low compared to contents in rice polishings and maize. Although lysine and methionine + cystine contents are variable, they are less than 0.1%.

4.2 Experiment 1

The diets were initially formulated to contain about 16% crude protein. On analysis, they contained 20 - 25% crude protein, however. This was due to the exceptionally high protein content in the cotton seed

Table 4.1 : **Chemical composition of various varieties of cassava root meal (CRM) cassava root tubers (CRT) and peels**

Item	Form and variety of cassava								
	1	2	3	4	5	6	7	8	9
DM	96.70	91.67	94.34	89.04	87.85	91.33	35.38	34.40	93.43
% of dry matter:									
CP	2.15	2.62	1.73	2.40	3.25	2.13	1.89	2.14	5.38
CF	2.83	3.55	3.53	3.50	-	(6.56)	3.76	3.25	(26.15)
EE	0.97	0.50	1.81	0.46	0.92	0.86	0.62	0.60	1.34
Ash	1.76	2.49	3.42	1.64	2.84	2.85	1.84	3.12	5.81
NFE	92.29	90.84	89.51	93.75	-	-	91.89	91.14	-
Ca	0.46	0.59	0.86	0.69	0.07	0.05	0.74	0.11	0.45
P	0.60	0.25	0.45	0.24	0.05	0.12	0.28	0.11	0.08
Starch							87.89	80.88	15.86

1 - CRM, peeled (ex NMC)
2 - CRM, peelled - Mzungu
3 - CRM, unpeeled - Kigoma variety
4 - CRM, peeled - sweet varieties
5 - CRM, sweet varieties
6 - CRT, peeled, soaked - sweet varieties
7 - CRT, peeled - Kigoma variety
8 - CRM, sweet varieties
9 - Cassava root peels, sweet varieties
( ) = NDF values

Samples 5, 6 and 9 were analysed at The National Institute of Animal Science, Denmark.

Table 4.2 : **Amino acid composition of cassava compared with rice polishings and maize (g amino acid/kg DM)**

Amino acid	CRM, peeled sweet var.	CRM, peeled sweet var.	Cassava root peels, sweet var.	Rice poli-shings	White maize
Alanine	1.26	0.63	2.10	10.96	7.66
Arginine	1.98	0.50	1.55	13.03	4.93
Aspartic acid	1.63	0.89	3.56	14.77	6.18
Cystine	0.25	0.14	0.54	3.19	2.39
Glutamic acid	4.23	2.91	4.08	21.90	19.20
Glycine	0.71	0.51	1.79	9.09	3.74
Histidine	0.38	0.17	0.71	4.53	3.14
Isoleucine	0.58	0.43	1.90	6.37	3.74
Leucine	0.91	0.69	2.95	11.72	13.07
Lysine	0.88	0.27	1.29	8.37	2.70
Methionine	0.23	0.17	0.55	3.05	2.36
Phenylalanine	0.55	0.41	1.87	7.47	5.12
Proline	0.75	0.51	1.93	7.83	9.85
Serine	0.73	0.45	2.08	7.88	5.25
Threonine	0.61	0.29	1.71	6.63	3.61
Tryptophan	0.35	0.16	0.48	2.17	0.77
Tyrosine	0.25	0.14	1.28	5.70	4.27
Valine	0.73	0.54	2.33	9.95	5.29

cake (36.8% CP) and kapok cake (30.5% CP).

In previous studies, contents of crude protein in cottonseed cake and kapok cake were 30 and 25% respectively. The diets contained 13 to 15% ether extract.

Consequently, rations were reformulated to contain 15 - 16% crude protein after four weeks (period 2). On analysis, they contained from 14.5 to 16.0% crude protein (air - dried basis). The diets were well balanced for contents of other nutrients including the content of metabolizable energy. Dustiness increased with increasing cassava levels (Table 4.3).

4.2.1 Experiment 1 - Growth study

Although the pigs were fed restrictedly, they consistently and progressively refused to finish their ration. During the experiment, the animals were housed in two pens and were fed in 12 feeding stalls which were used in turn. Each animal was fed for about two hours. To avoid problems of fouling the feed, refusals were collected and weighed after a feeding time allowance of two hours.

Cases of diarrhoea were observed in the first weeks and were especially serious in treatment A_1 (control) which contained 45% maize. In the other treatments

Table 4.3 : Chemical composition of diets in experiment 1 (period 2) and experiment 2

Item	Treatment			
	A_1	B_1	C_1	D_1
	Level of CRM in diet (%)			
	0	20	40	60
Dry matter (DM)	90.3	90.2	89.7	91.6
% of DM:				
Crude protein (CP)	17.68	16.20	16.16	16.81
Crude fibre (CF)	6.48	6.36	6.58	8.90
Ether extract (EE)	6.25	5.81	5.48	5.05
Ash	5.32	5.21	5.18	5.07
Nitrogen free extractive (NFE)	64.57	66.42	66.16	64.17
Calcium (Ca)	0.71	0.74	0.81	0.88
Phosphorus (P)	0.69	0.88	0.79	0.87
Lysine	0.78	0.71	0.66	0.62
	(0.70)	(0.64)	(0.59)	(0.56)
Methionine + cystine	0.67	0.57	0.50	0.43
	(0.60)	(0.52)	(0.45)	(0.39)

diarrhoea was sporadic. Feed refusal was also rampant in treatment A . Cashewnut cake and kapok cake were suspected to be the causes of these problems, and their levels were reduced to 0 and 11%, respectively in period 2, i.e. after 28 days. In a separate trial, the kapok cake used proved to seriously reduce feed intake in a hominy feed diet.

Despite the change in diets, feed refusal persisted especially in treatment A_1 . Diarrhoea continued to occur sporadically in this treatment up to the 7th week. By the 5th week, pigs in treatment A_1 had assumed the lowest gains, and they continued to lag behind for the rest of the experimental period (Figure 4.1). They had a significantly lower growth rate ($P < 0.01$) and feed efficiency ($P < 0.05$) than the rest of the animals. Pigs in treatment B_1 grew faster than pigs in treatment C_1 ($P < 0.05$). No particular trends were evident with increasing levels of cassava.

Three animals, two from treatment A_1 and one from treatment D_1, were euthanized before reaching slaughter weight. One of the pigs euthanized in treatment A_1 persistently refused feed, and after 161 days had gained only 40 kg (248 g/day). The other pigs reached 83 and 77 kg liveweight and thereafter they started to lose condition accompanied by feed refusal which culminated in hindquarter incoordination.

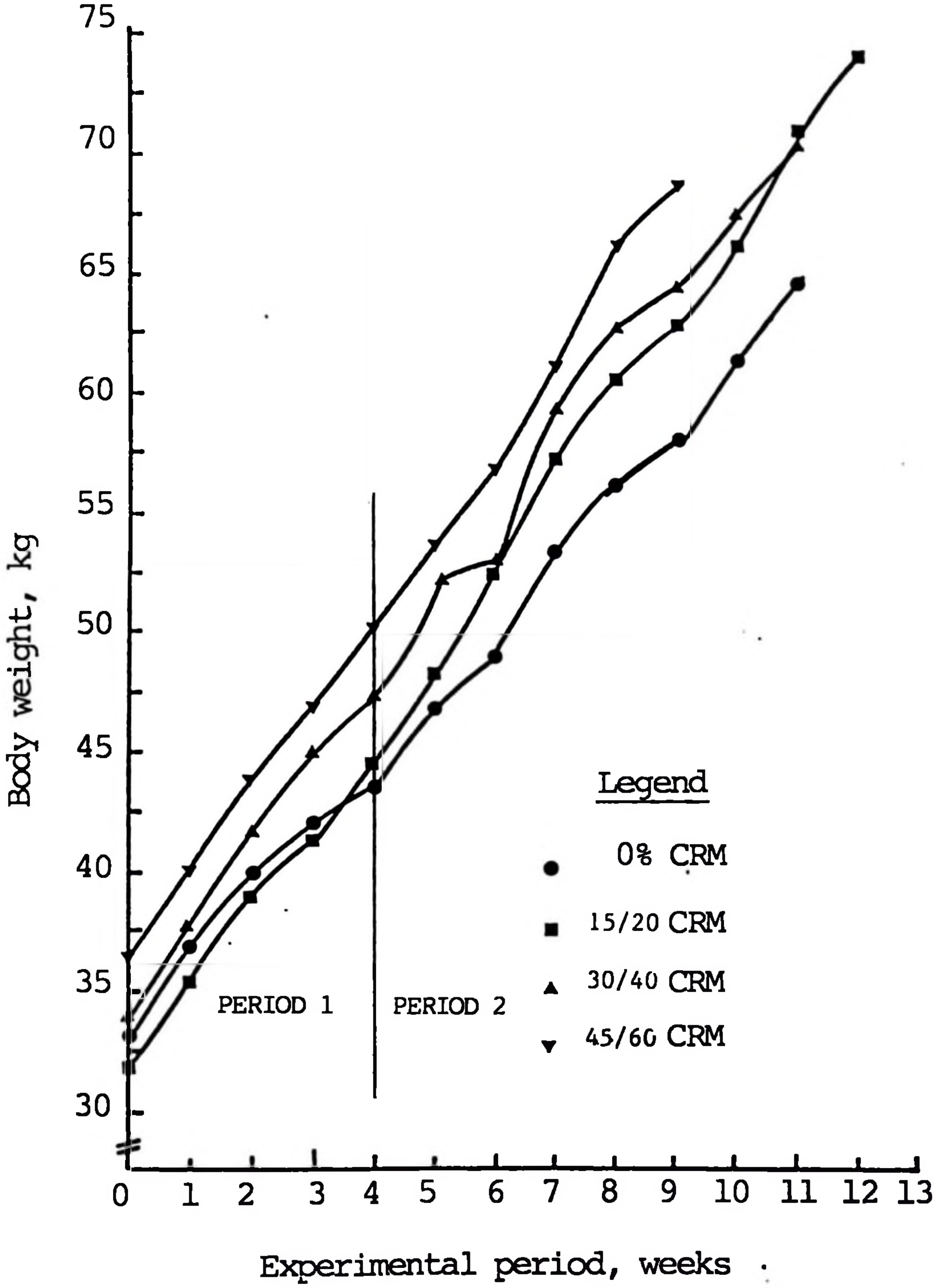


Figure 4.1. Growth curves of pigs in experiment 1.

On autopsy, all fat in the body was necrotic. Similarly, all the animals included in the experiment for more than 18 weeks had necrotic fat, and the kidney fat was condemned. They had different degrees of fat necrosis in their bodies. The smallest animals were the most retarded in growth, and two of those euthanized were among the smallest. They were characterized by dwarfism.

At slaughter, animals in treatment A_1 had significantly shorter carcasses ($P < 0.01$). The level of cassava root meal did not influence organ weights. However, all the pigs had excessive kidney fat compared to pigs in other studies previously carried out by the author and also to pigs in experiments 3, 5 and 6. The kidney fat and backfat as well was extremely hard and solidified in warm food. Most of the backfat was trimmed off and sold for cooking, but customers complained about the fat quality which was similar to that of fat from ruminants. Customers prefer lard to be liquid at room temperature (25°C).

Although the saponification value or iodine number were not determined, the difference from normal pig fat was very apparent.

Table 4.4 : Performance of pigs in experiment 1

Levels of CRM in diet(%)	Treatment				SE mean
	A_1	B_1	C_1	D_1	
	0	15/20	30/40	45/60	
Animals/treatment	6	6	6	6	
Initial weight, kg	32.8	31.7	33.9	36.5	3.5
Av. daily gain, g	386^{a}	504^{b}	457^{c}	487^{bc}	29.0
Av. daily feed, g DM	2083^{2}	2089	2024	2119^{a}	36.6
Feed/gain ratio	5.3^{a}	4.4^{b}	4.5^{b}	4.1^{b}	0.21
Weight of thyroid, g	7.0	6.4	7.4	6.6	-
Empty body weight-E, %	79.0^{2}	79.4	80.2	79.7^{1}	0.8
Weight of kidney fat, g	988	1042	1042	806^{1}	82.0
Carcass length, cm	86.6^{2a}	92.3^{b}	93.8^{b}	93.7^{1b}	1.11
Backfat thickness, mm	37^{2a}	32^{ab}	34^{ab}	31^{ab}	2.0

1 - Average of five pigs. One pig was euthanized

2 - Average of four pigs. Two pigs were euthanized

a, b, c, - values in the rows bearing different superscripts are significantly different ($P < 0.05$)

Average daily gain values are corrected for differences in initial weight.

4.2.2 Experiment 2 - Digestibility study

The digestibility coefficients of the diets used in this study are presented in Table 4.5. The metabolizable energy and nitrogen retention values are presented in the same table. There were no significant differences between treatments for most of the nutrients. The values for digestibility of crude fibre and ether extract, although significantly different, were inconsistent. In general, all diets were well digested, as shown by the high digestibility coefficients of DM, OM, CP and NFE, as well as the high ME values.

The feed refusal experienced in the growth study did not occur here. The feeding level was lower in this study, and animals had no access to the period 1 diets. However, one of the pigs in treatment B_1 developed diarrhoea during one of the collection periods.

4.3 Experiments 3 and 4

The chemical composition of diets used in experiments 3 and 4 is shown in Table 4.6.

The diets cotained 14.4 to 16.4% crude protein (air-dried basis). They were fairly well balanced and contained adequate nutrients for normal growth in

Table 4.5 : Digestibility coefficients and nitrogen retention in experiment 2

Item	Treatment				SE mean
	A_1	B_1	C_1	D_1	
Levels of CRM (%)	0	20	40	60	
DM	78.5	80.2	79.3	79.1	0.67
OM	80.5	82.3	81.9	81.1	0.68
CP	77.3	76.0	76.5	76.0	1.66
CF	25.1^{a}	34.3^{ab}	24.1^{a}	37.5^{b}	3.27
EE	77.9^{a}	78.8^{a}	88.1^{b}	85.9^{b}	1.25
Ash	42.8	40.8	31.5	42.5	4.34
NFE	87.2	89.1	88.3	88.1	0.93
ME, MJ/kg DM	14.66	14.84	14.78	14.66	0.12
Nitrogen balance, g/day	10.9	7.3	11.3	9.3	1.74
N-retention, % of intake	29.0	21.2	33.3	26.3	3.18
N-retention, % of digested	41.1	28.8	43.6	33.9	4.37
ADG, g	286	249	392	383	67.9

ADG - Average daily gain

a, b - Values in the rows bearing different superscripts are significantly different ($P < 0.05$)

Table 4.6 : Chemical composition of diets in experiments 3 and 4

	Treatment					
	A_2 Control	B_2 CRM	C_2^1 CRT	Protein conc.	Cassava tubers	D_2 Rice polishings
Dry matter	91.21	92.07	92.16	92.94	34.40	94.03
% of dry matter:						
Organic matter	89.71	94.04	92.80	88.31	96.88	93.49
Crude protein	17.96	15.62	17.67	32.71	2.14	15.29
Crude fibre	19.58	7.82	9.50	10.32	3.25	4.75
Ether extract	6.23	2.47	5.73	7.83	0.60	7.38
Ash	10.29	5.97	7.20	11.69	3.12	6.51
NFE	54.94	68.12	59.90	37.45	91.14	66.03
Calcium	0.52	1.25	1.05	2.23	0.11	0.90
Phosphorus	0.67	0.66	0.71	1.06	0.11	0.64
Lysine	-	0.64	0.79	1.53	-	1.02
		(0.58)	(0.71)			(0.92)
Methionine + cystine	-	0.47	0.57	1.12	-	0.74
		(0.42)	(0.52)			(0.67)

1. Based on dry matter consumption of 51 to 52% cassava root tubers.

( ) - Percent in air dried feed.

accordance with NRC (1979) recommendations. However, the contents of lysine and sulphur amino acids (SAA) are below the ARC (1981) recommendations in all the diets except diet D_2, which had the highest amino acid content and the lowest crude fibre content because the rice polishings was of very good quality with very low fibre content and a high proportion of broken rice. The hydrocyanic acid (HCN) content in the cassava used in diet B_2 was 25 mg/kg. This diet was very dusty. The commercial diet (Control A_2) did not differ significantly from the other diets in chemical composition. The amino acid contents in cassava, rice polishings and maize is contained in Table 4.2. The amino acid content in cassava is very low and quite high in rice polishings. In this respect the rice polishings is much superior as shown by the specially high levels of lysine and methionine + cystine. The rice polishings product was also superior to maize in all essential amino acids except leucine.

4.3.1 Experiment 3 - Growth study

4.3.1.1 Growth and feed utilization

Table 4.7 shows the growth performance of pigs fed four different diets - A_2, B_2, C_2 and D_2. Feed consumption was high. It was the highest of all in a series of four experiments. The growth rates were also high with an average gain of over 600 g/day for all the treatments (Plates 4 and 5). However, feed conversion

Plate 4. Pigs fed cassava root meal diet

Plate 5. Pigs fed soaked cassava root tubers

Table 4.7 : Growth performance of pigs in experiment 3

Item	Treatment				SE mean
	A_2	B_2	C_2	D_2	
	Control	CRM	CRT	Rice pol.	
Initial weight, kg	33.8	32.0	34.3	31.5	2.51
Final weight, kg	89.4	89.6	89.2	89.0	0.66
Days	95.5	94.3	89.2	89.8	9.33
Av. daily gain, g	625	635	608	660	46.9
Barrows	673	694	597	741	
Gilts	576	594	631	579	
Av. daily feed:					
g DM	2581	2555	2437[1]	2467	
ME, MJ	37	36	38	40	
Feed/gain ratio:					
kg DM/kg gain	4.44	4.19	4.05	3.89	
ME, MJ/kg gain	64	59	63	63	
Relative performance:					
Av. daily gain	100	102	97	106	
Av. daily feed	100	99	95	96	
Feed efficiency	100	105	108	112	

[1] Consisting of: 1234 g cassava and 1203 g protein concentrate . Consumption of fresh cassava root tubers and protein concentrate from 20 to 90 kg is 406 and 152 kg, respectively.

was poor for all groups requiring about 62 MJ ME/kg gain.

There were no significant differences in growth rate between treatments. This is illustrated in Figure 4.2. The largest difference was only 9 grams. Daily feed intake was also very similar. Pigs fed rice polishings had the highest feed efficiency and growth rate, but the differences were not statistically significant. Compared with the basal diet, diets C_2 and D_2 had 8% and 12% higher efficiencies. When compared on an ME basis, (ME/kg gain), the differences are very insignificant. In this respect the CRM diet (B_2) had the highest efficiency. The other three diets had similar efficiencies.

Pigs on the CRT diet (C_2) consumed 3.49 kg fresh cassava and 1.2 kg protein supplement per pig per day. The intake of cassava was about 50% of the dry matter intake. The pigs tended to overconsume the protein concentrate, and hence, it was limited to a maximum of 1.5 kg/pig/day. The pigs at the protein concentrate first. Pigs in this treatment had loose faeces, but diarrhoea was not observed in any of the treatments. The fresh cassava was soaked in static water before use. However, if soaking was continued for several days, the cassava softened, and the starch started to break off. Any degree of softening was disliked by the pigs, and

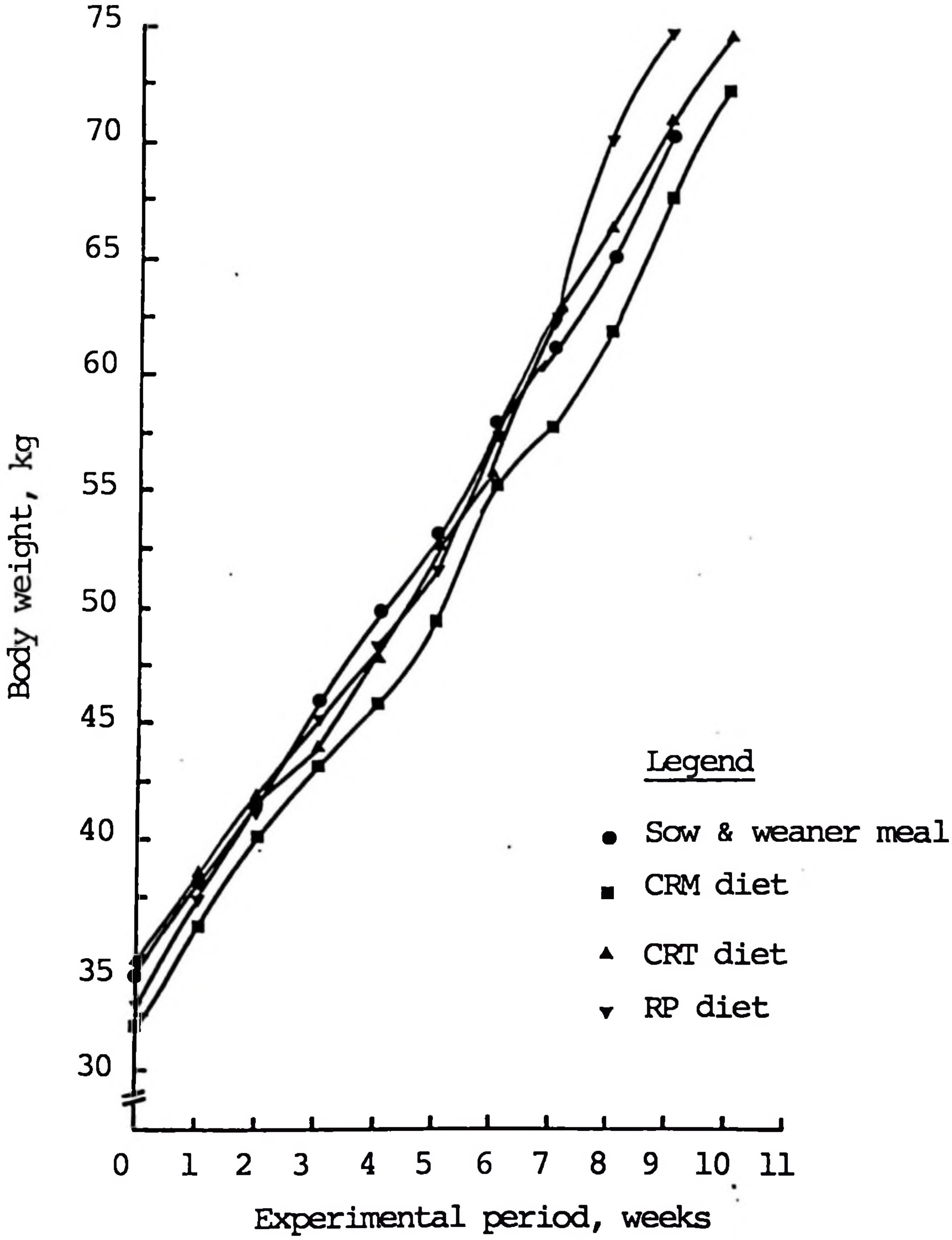


Figure 4.2. Growth curves of pigs in experiment 3.

completely softened roots were rejected.

During the experiment a disease outbreak affected the pigs. They developed characteristic skin lesions on their backs but concentrated in the shoulder region. The lesions started as small red swellings, which attracted flies. The disease was suspected to be erysipelas or parakeratosis, but was never confirmed. On the basis of the high calcium contents in the diets and the fact that the premix contained no zinc, the diets would be deficient in zinc which induces parakeratosis.

The C_2 pigs were severely affected. The disease was not restricted to the experimental animals. It had occurred previously and was to occur again in subsequent experiments. Barrows had higher liveweight gains than gilts. The average daily gain (ADG) was 674 g and 590 g for barrows and gilts, respectively. These differences were, however, not significant.

4.3.1.2 Carcass characteristics and organ weights

The carcass and organ measurements are contained in Table 4.8 The control group had significantly lower percentages of empty body weight. Compared with B_2, the difference was highly significant ($P<0.01$), with C_2 it was significant ($P<0.05$) and with D_2 it was very highly significant ($P < 0.001$). The weight of kidney

Table 4.8 : Carcass characteristics and organ weights of pigs in experiment 3

Item	Treatment				SE mean
	A_2 Control	B_2 CRM	C_2 CRT	D_2 Rice pol.	
% empty body weight	76.2^{a}	79.6^{b}	78.6^{b}	79.8^{b}	0.61
Weight of kidney Fat, g	717^{ab}	679^{a}	633^{a}	850^{b}	44.2
Carcass length, cm	94.4	92.5	94.1	93.1	1.08
Backfat thickness, mm	34	34	31	33	1.5
Weight of kidney, g	113	128	122	117	7.6
Weight of heart, g	254	239	256	251	12.2
Weight of liver, g	1542^{a}	1725^{b}	1542^{a}	1471^{a}	66.8
Weight of thyroid, g	10.3^{a}	7.3^{b}	5.9^{b}	6.3^{b}	0.75
GITF, kg	10.6^{a}	9.1^{ab}	8.8^{ab}	8.5^{b}	0.64
GITE, kg	5.1	4.6	4.8	4.6	0.27
SINTF, kg	3.9	3.6	3.2	3.1	0.29
SINTE, kg	2.2^{a}	1.9^{b}	1.9^{b}	1.7^{b}	0.12
LINTE, kg	2.0	2.0	2.3	1.9	0.17
SINTL, cm	2093	2214	2162	2168	47.7
LINTL, cm	670^{a}	573^{b}	598^{b}	597^{b}	18.9
GIT fill, kg	5.5	4.5	4.0	4.0	0.68
SINT fill, kg	1.7	1.7	1.3	1.4	0.30
LINT fill, kg	3.9^{a}	2.1^{b}	2.8^{b}	2.2^{b}	0.31

GITF = Gastrointestinal tract full.
GITE = Gastrointestinal tract empty
SINTF = Small intestine full
SINTE = Small intestine empty
LINTF = Large intestine full
LINTE = Large intestine empty
SINTL = Small intestine length
LINTL = Large intestine length
GIT = Gastrointestinal tract
SINT = Small intestine
LINT = Large intestine
a, b, = values in the rows bearing different superscripts are significantly different ($P < 0.05$).

fat was significantly higher in treatment D_2 compared to B_2 ($P < 0.05$) and C_2($P < 0.01$). The carcass length, backfat thickenss and weights of most organs were not significantly influenced by treatment. Quite unexpectedly, the control pigs had significantly heavier thyroids ($P < 0.05$). Pigs fed the soaked, fresh cassava (C_2) had the lightest thyroids, but they did not differ significantly from those of B_2 and D_2. The CRM (B_2) pigs had significantly heavier livers than pigs in other treatments ($P < 0.05$).

There were quite significant differences in gut measurements between the control and the experimental groups. The weight of the gastrointestinal tract with contents was significantly higher in treatments A_2 than in D_2 ($P < 0.05$). It tended to decrease gradually from A_2 to D_2. A similar trend was observed for gut fill and small intestine with contents. Pigs in treatment A_2 had significantly heavier small intestines (empty) and large intestines (with contents) than B_2 and D_2 pigs ($P < 0.05$). Treatment C_2 pigs also had significantly heavier large intestines (with contents) than B_2 and D_2 pigs ($P < 0.05$). The length and fill of the large intestine were significantly higher for treatment A_2 than for the rest ($P < 0.05$).

There were no significant differences in organ weights between sexes. Barrows had significantly thicker backfat than gilts ($P < 0.05$) and tended to have heavier kidney fat, shorter carcasses and less gut fill.

4.3.2 **Experiment 4 - Digestibility study**

The digestibility coefficients of the diets used in experiment 4 are given in Table 4.9. There were significant differences between treatments, especially between treatment A_2 and the rest. The digestibility of dry matter and organic matter was significantly higher in diets C_2 and D_2 than in diets A_2 and B_2 ($P < 0.01$). The digestibility of crude protein was significantly higher in diet C_2 than in diet B_2 ($P < 0.01$). There were significant differences in digestibility of crude fibre and ether extract ($P < 0.05$). The rice polishings diet (D_2) had the highest NFE digestibility ($P < 0.05$). Diets A_2 and B_2 had significantly lower metabolisable energy contents than diets C_2 and D_2 ($P < 0.05$). D_2 had the highest metabolisable energy content, while B_2 had the lowest one. Nitrogen retention was highest in A_2 and C_2 diets and lowest in B_2 , but daily gains were highest for the C_2 diet group.

4.4 **Experiment 5**

The chemical composition of diets is shown in Table 4.10. The diets were formulated to contain 16% crude protein (air-dried basis). On analysis, they were found to contain much lower levels, i.e. 12 - 14%, due to much lower contents of crude protein in the oilcakes as compared to previous batches. These cakes also had a higher crude fibre content. Consequently, the diets had fairly high levels of crude fibre, especially diets A_3 and C_3 . These diets also contained high levels of ash.

The lysine and SAA content in the diets meet the NRC (1979) standards for finishing pigs, but are far below the ARC (1981) requirements for lysine of growing-finishing pigs and only meet

Table 4.9 : **Digestibility coefficients of diets in experiment 4**

Item	Treatment				SE mean
	A_2	B_2	C_2	D_2	
	Control	CRM	CRT	Rice pol.	
Dry matter (DM)	79.6^{a}	79.4^{a}	85.1^{b}	86.7^{b}	0.96
Organic matter	81.5^{a}	82.1^{a}	86.9^{b}	88.9^{b}	0.90
Crude protein	76.5^{ab}	72.4^{a}	80.7^{b}	76.6^{ab}	1.26
Crude fibre	63.1^{a}	25.1^{b}	52.4^{c}	39.2^{d}	3.23
Ether extractives	75.7^{ab}	64.6^{a}	88.5^{b}	87.3^{b}	5.16
Ash	57.1^{a}	36.3^{b}	61.9^{a}	54.8^{a}	3.23
NFE	90.6^{a}	91.6^{a}	93.7^{a}	95.6^{b}	1.20
N retention, g/day	7.6	4.2	7.6	6.8	1.18
N retention, % of intake	36.3	22.6	37.1	37.1	6.07
N retention, % of digested	46.2	31.1	45.7	48.7	7.86
Metab. energy, MJ/kgDM	14.4^{a}	13.7^{a}	15.4^{b}	16.1^{b}	0.19
Av. daily gain, g	285^{a}	160^{a}	357^{b}	178^{a}	45.4

a, b, c and d = values in the rows bearing different superscripts are significantly different (P < 0.05).

Table 4.10 : **Chemical composition of diets in experiment 5**

Item	Protein conc.	Cassava tubers	treatment		
			A$_3$[1] CRT+CSC+SC	B$_3$ CRM+CSC	C$_3$ CRM+CSC+SC
Dry matter (DM)	94.54	38.35	92.34	91.94	93.15
% of DM:					
Crude protein	26.97	1.75	13.01	15.16	13.42
Crude fibre	17.51	3.48	10.38	7.66	11.82
Ether extract	8.40	0.59	4.50	4.78	4.22
Ash	17.70	3.23	10.41	5.36	9.11
NFE	29.42	90.97	61.70	67.04	61.43
Calcium	2.12	0.28	1.00	1.10	0.92
Phosphorus	1.12	0.21	0.63	0.62	0.64
Lysine	1.44	-	0.63	0.71	0.64
			(0.57)	(0.64)	(0.58)
Methionine + cystine	1.23	-	0.54	0.52	0.57
			(0.49)	(0.47)	(0.51)

[1]Based on average dry matter consumption of 56.2% fresh cassava roots and 43.8% protein concentrate.

() Percentage in air-dried feed.

requirements for SAA of finishing pigs due to low amino acid contents in the feeds (Table 4.11). The table shows that cottonseed cake and sunflower cake are comparable in amino acid content and poorer than soybeans and fishmeals. Lysine contents are comparatively lower in the two oilcakes.

4.4.1 Growth and feed utilization

Table 4.12 shows the performance of growing-finishing pigs fed two forms of cassava (dry versus fresh) and two protein supplements (cottonseed cake versus sunflower cake). The aim in this experiment was to use fresh, unpeeled cassava in one of the treatments (A_3). However, the pigs consistently peeled the chopped cassava tubers, ate the parenchyma and left the peels. These were collected as refusals. After four weeks, the cassava tubers were peeled before they were chopped and fed.

During the first and second weeks, pigs in treatment C_3 had diarrhoea. The smallest pig, which weighed 12 kg at the start, did not recover and had diarrhoea for six weeks until it weighed over 20 kg. Mild diarrhoea was observed in treatment A_3 during the fourth week. Severe diarrhoea affected all the pigs in treatment A_3 during the sixth week. This is shown by the slowing down of growth in Figure 4.3.

During the same time, there was an outbreak of skin diseases as in the previous experiment. The characteristic lesions were more severe in treatment A_3 , and flies worsened the condition.

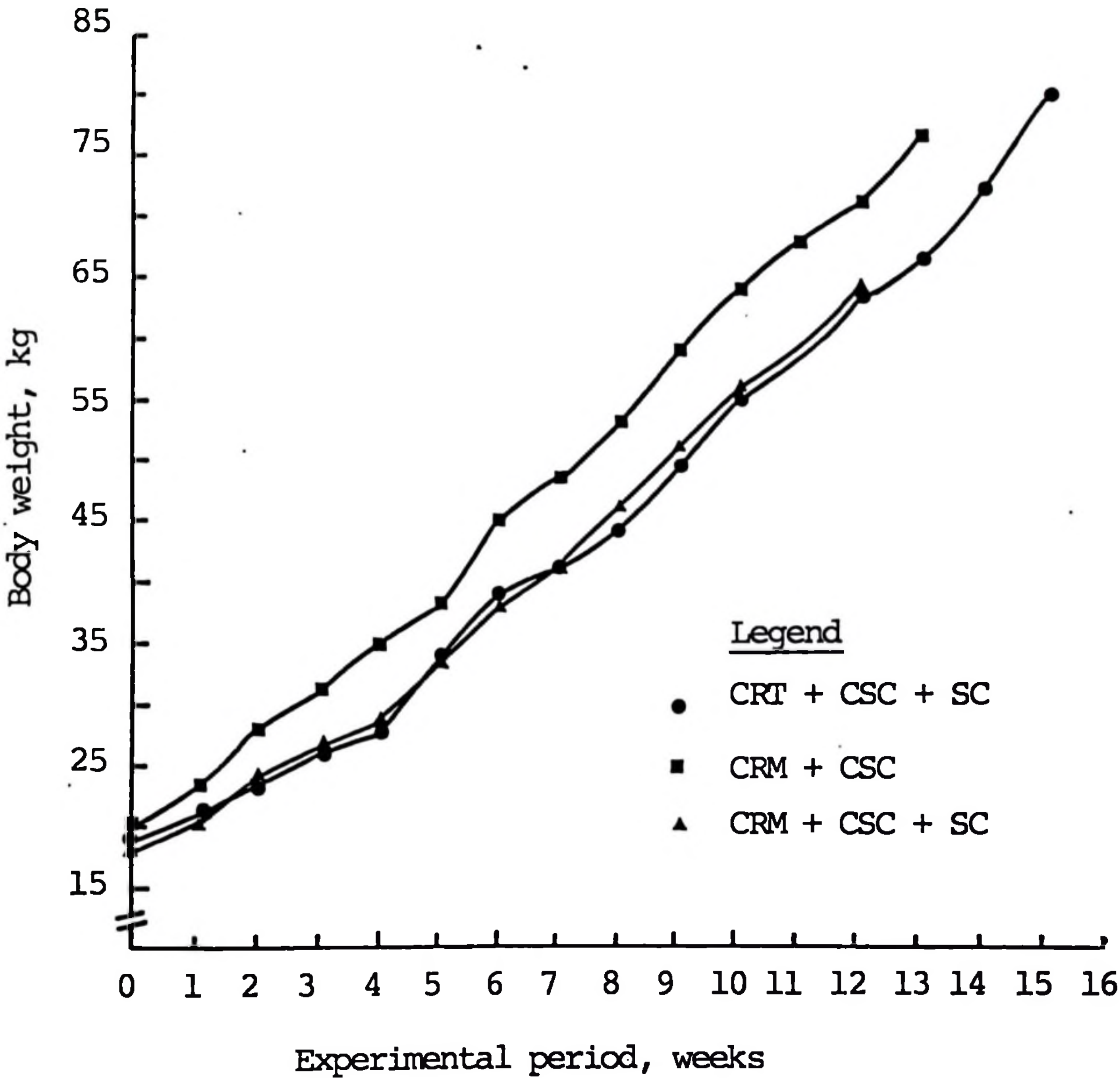


Figure 4.3. Growth curves of pigs in experiment 5.

Table 4.11 :Amino acid composition of cottonseed cake (CSC), sunflower cake (SC), soybeans (SB) and fishmeal (FM). In grams per kg dry matter

Amino acid	CSC	SC	SB	FM_M	FM_K
Alanine	14.90	13.91	18.28	37.16	41.02
Arginine	40.49	29.70	32.53	38.09	38.86
Aspartic acid	32.85	29.84	47.55	54.39	60.91
Cystine	5.62	5.49	6.76	6.05	6.07
Glumatic acid	72.48	68.84	76.56	84.24	88.81
Glycine	15.62	18.67	18.38	38.53	38.28
Histidine	9.74	7.89	11.12	18.39	21.49
Isoleucine	12.84	14.74	20.05	27.22	30.46
Leucine	22.25	20.83	31.66	44.24	49.31
Lysine	14.18	10.71	25.86	45.34	48.67
Methionine	5.50	7.46	6.17	16.41	19.18
Phenylalanine	19.97	15.62	20.99	25.05	27.79
Proline	15.32	15.45	22.98	27.66	29.61
Serine	17.23	14.90	22.74	25.58	26.79
Threonine	12.20	11.73	16.59	24.97	27.70
Tryptophan	4.41	4.54	6.10	6.70	7.49
Tyrosine	11.66	9.08	16.04	11.58	22.09
Valine	17.88	17.53	21.49	31.28	36.49

Suffix M to FM = ex Mwanza. Suffix K to FM = ex Kigoma

Table 4.12 : Growth performance of pigs in experiment 5

Item	Treatment			SE mean
	A_3	B_3	C_3	
Initial weight, kg	19.0	20.5	18.0	1.91
Final weight, kg	89.8	89.8	90.3	0.48
Days	130	111	127	11.0
Barrows	121	102	121	
Gilts	140	120	133	
Av. daily gain, g	551	646	589	46.6
Barrows	607	691	643	
Gilts	495	602	535	
Av. daily feed, g dry matter	1873[1]	2102	2026	
Feed/gain ratio, kg DM/ kg gain	3.45	3.36	3.56	
Relative performance				
Av. daily gain	100	116	107	
Av. daily feed	100	112	108	
Feed efficiency	100	103	97	

[1]Consisting of 1052 g cassava and 821 g protein concentrate

Consumption of fresh cassava root tubers and protein concentrate from 20 to 90 kg is 383 and 112 kg, respectively.

There were no significant differences in rate of gain between the treatments (Fig. 4.3). Despite the disease setbacks, the pigs had satisfactory weight gains in all the treatments. The feed conversion was also satisfactory and better than in the previous experiment. The pigs receiving mainly cottonseed cake as the protein concentrate (B_3) had the highest feed intakes and daily gains (Table 4.12). Replacing half the cottonseed cake in CRM with sunflower cake (C_3) slightly reduced feed intakes and daily gains. Feed conversion was not significantly affected by treatment. Diet B_3 had the highest feed efficiency.

Feed intake was much lower in this experiment than in the previous experiment. In treatment A_3, pigs consumed 2.97 kg fresh cassava and 1.0 kg protein concentrate. Cassava formed 56.2% of the dry matter intake.

Barrows gained 647 g/day while gilts gained 544 g/day, but these differences were not statistically significant.

4.4.2 Carcass characteristics and organ weights

Table 4.13 shows the carcass and organ measurements. Most of these parameters were not influenced by treatment. Pigs in treatment A_3 had significantly more kidney fat than B_3 and C_3 pigs ($P < 0.05$), while B_3 pigs had significantly shorter carcasses than C_3 pigs ($P < 0.05$). Pigs receiving diet C_3 had significantly heavier small intestines (empty) than pigs fed diets A_3 and B_3

Table 4.13 : Carcass characteristics and organ weights of pigs in experiment 5

Item	Treatment A_3	B_3	C_3	SE mean
% empty body weight	76.0	79.4	78.0	0.98
Killing out percentage	68.7	72.3	70.4	1.08
Weight of kidney fat, g	756^{a}	611^{b}	575^{b}	39.4
Carcass length, cm	93.9^{ab}	90.0^{a}	95.1^{b}	0.87
Backfat thickness, mm	32	35	32	1.5
Weight of kidney, g	129	125	129	3.7
Weight of heart, g	260	255	257	10.5
Weight of liver, g	1431	1613	1600	54.5
Weight of spleen, g	135	146	148	10.9
Weight of thyroid, g	8.1	7.6	6.9	0.75
GITF, kg	11.1	9.3	9.6	0.68
FITE, kg	4.7	4.0	4.7	0.45
SINTF, kg	3.7	3.7	3.7	0.25
SINTE, kg	1.8^{a}	1.6^{a}	2.3^{b}	0.12
LINTF, kg	4.9	4.2	4.8	0.29
LINTE, kg	2.0	1.7	2.2	0.31
SINTL, cm	2397	2301	2371	71.5
LINTL, cm	677	566	667	16.5
GIT fill, kg	6.4	5.3	4.9	0.80
SINT fill, kg	1.9	2.1	1.4	0.30
LINT fill, kg	2.9	2.5	2.6	0.37

GITF = Gastrointestinal tract, full.
GITE = Gastrointestinal tract, empty
SINTF = Small intestine, full.
SINTE = Small intestine empty
LINTF = Large intestine, full
LINTE = Large intestine, empty
SINTL = Small intestine length.
LINTL = Large intestine length
GIT = Gastrointestinal tract.
SINT = Small intestine
LINT = Large intestine
a, b = values in the rows bearing different superscripts are significantly different ($P < 0.05$).

($P < 0.05$). However, pigs receiving diet B_3 tended to have smaller large intestines than pigs receiving A_3 and C_3 diets.

The carcass and organ measurements were not significantly influenced by sex. However, barrows tended to have shorter carcasses, thicker backfat and higher gut fill.

4.5 Experiment 6

The diet used in this experiment was well balanced for the various nutrients. However, it had a slightly lower protein content (14.6% CP on an air-dried basis) than the recommended levels. This diet was dusty. This experiment was conducted at the same time as experiment 5.

4.5.1 Growth and feed utilization

The performance of pigs fed the standard CRM diet is shown in Table 4.15. As in the previous experiments, the pigs had an adaptation period of 7 days. At the beginning of the adaptation period the pigs weighed from 19 to 22 kg.

During the adaptation period, feed consumption, feed efficiency and daily gains were extremely high in the pigs fed *ad libitum*. The average daily gain and feed intake were 849 g and 2.19 kg, 869 g and 1.71 kg, 274 g and 1.13 kg and 203 g and 1.15 kg for treatments A_4 , B_4, C_4, and D_4, respectively. The high feed intake in the groups fed *ad libitum* results in greater gut fill. These differences brought about the differences in the initial

Table 4.14 : **Chemical composition of diet used in experiment 6**

Item	Percent	
Dry matter (DM)	90.71	
% of dry matter:		
Crude protein	16.10	
Crude fibre	8.28	
Ether extract	3.60	
Ash	11.12	
NFE	60.90	
Calcium	0.66	
Phosphorus	0.58	
Lysine	0.64	(0.58)
Methionine + cystine	0.48	(0.43)
Metab. energy, MJ/kg DM	13.73	

() = percentage in air-dried feed

Table 4.15 : Growth performance of pigs in experiment 6

	Treatment				SE mean
	Ad libitum		Restricted		
	Barrows A_4	Gilts B_4	Barrows C_4	Gilts D_4	
Initial weight, kg	28.2	25.0	20.8	22.3	1.56
Av. daily gain, g	726^a	563^b	564^b	538^b	22.17
Days	84^a	116^b	126^b	129	
Av. daily feed, g DM	2542	1963	1633	1768	
Metab. energy MJ (estimated)	35	27	22	24	
Feed/gain ratio:					
kg DM feed/kg gain	3.46	3.51	2.99	3.34	
ME, MJ/kg gain	47	48	41	46	
Relative performance:					
Av. daily gain (corrected)	100	78	78	74	
Av. daily feed	100	77	64	70	
Feed efficiency	100	99	114	103	
Effect of sex:		Barrows	Gilts		
Av. daily gain		645^a	551^b		22.17
Av. daily feed		2088	1866		
Feed/gain ratio		3.23	3.43		
Effect of plane of nutrition		Ad libitum	Restricted		
Av. daily gain		644^a	551^b		22.17
Av. daily feed		2253	1701		
Feed/gain ration		3.49	3.17		

NOTE: Average daily gain and feed/gain values are corrected for differences in initial weights

A and b = values in the rows bearing different superscripts are significantly different ($P < 0.001$).

Table 4.15 : **Growth performance of pigs in experiment 6**

	Treatment				SE mean
	Ad libitum		Restricted		
	Barrows A_4	Gilts B_4	Barrows C_4	Gilts D_4	
Initial weight, kg	28.2	25.0	20.8	22.3	1.56
Av. daily gain, g	726^a	563^b	564^b	538^b	22.17
Days	84^a	116^b	126^b	129	
Av. daily feed, g DM	2542	1963	1633	1768	
Metab. energy MJ (estimated)	35	27	22	24	
Feed/gain ratio:					
kg DM feed/kg gain	3.46	3.51	2.99	3.34	
ME, MJ/kg gain	47	48	41	46	
Relative performance:					
Av. daily gain (corrected)	100	78	78	74	
Av. daily feed	100	77	64	70	
Feed efficiency	100	99	114	103	
Effect of sex:		Barrows	Gilts		
Av. daily gain		645^a	551^b		22.17
Av. daily feed		2088	1866		
Feed/gain ratio		3.23	3.43		
Effect of plane of nutrition		Ad libitum	Restricted		
Av. daily gain		644^a	551^b		22.17
Av. daily feed		2253	1701		
Feed/gain ration		3.49	3.17		

NOTE: Average daily gain and feed/gain values are corrected for differences in initial weights

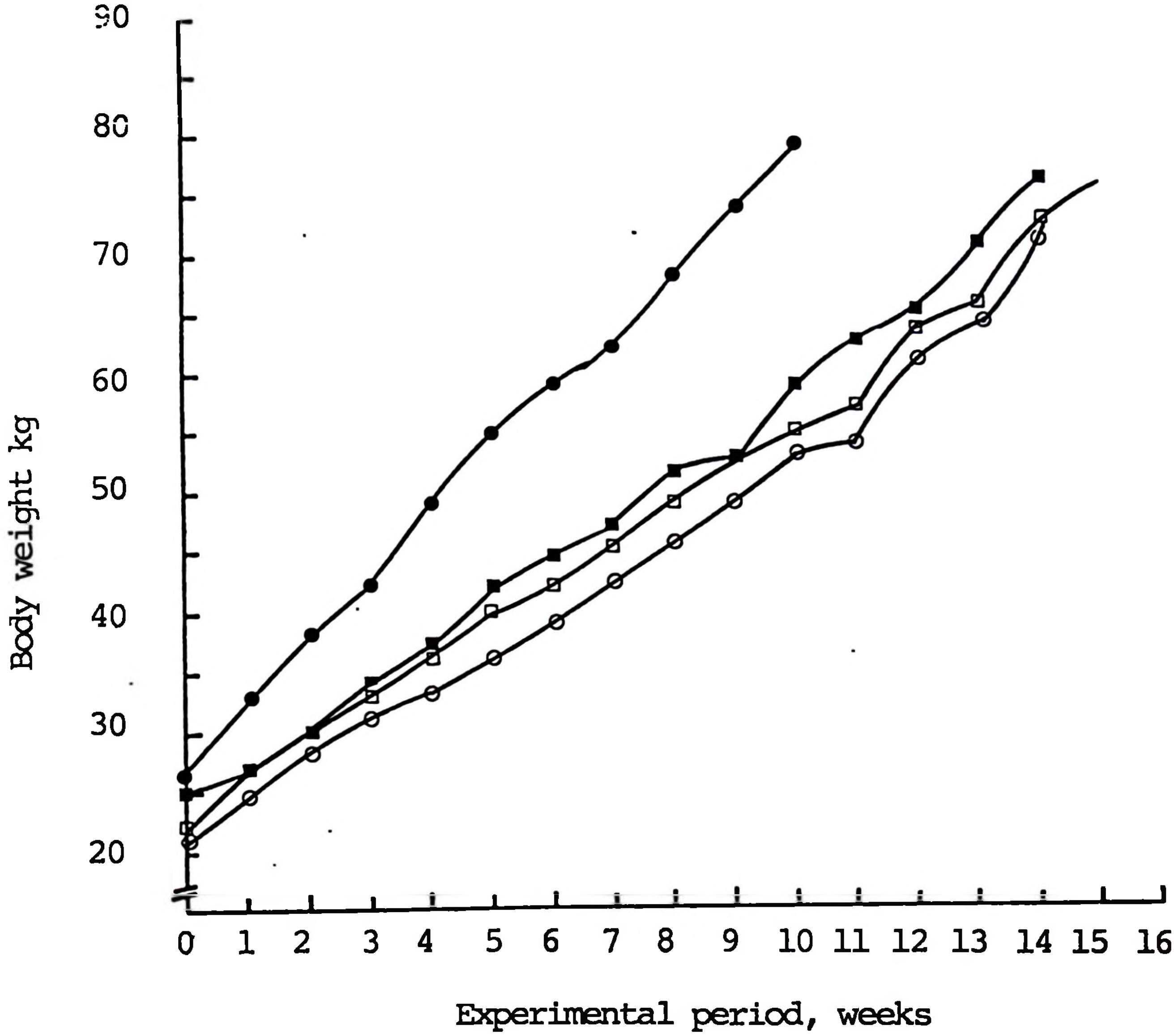
A and b = values in the rows bearing different superscripts are significantly different ($P < 0.001$).

weight at the beginning of the experimental period.

Feed intake and growth rate dropped drastically after the adaptation period in the *ad libitum* fed pigs, while it improved for the restricted pigs. There was sporadic diarrhoea in treatments B_4, C_4 and D_4 up to the third week.

An outbreak of skin disease occurred in the 7th to 10th week, as in the previous experiments. These lesions were more severe in the pigs fed restrictedly. Otherwise the animals were in good health.

The plane of nutrition had a significantly effect on growth rate ($P < 0.001$). Pigs fed *ad libitum* had significantly higher growth rates than restricted pigs ($P < 0.001$). Barrows also had significantly higher growth rates than gilts ($P < 0.001$). Barrows fed *ad libitum* grew significantly faster than gilts fed *ad libitum*, restricted barrows and restricted gilts. However, *ad lib.* fed gilts, restricted gilts and restricted barrows had similar growth (Figure 4.4). Thus, the interaction between sex and plane of nutrition on daily gain was significant ($P < 0.01$). The differences in growth rate and daily feed intake between A_4 and the average of B_4 C_4 and D_4 pigs were 23% and 30%, respectively. However, the restricted barrows had a 14% higher efficiency of feed conversion than the *ad libitum* barrows (Table 4.15). On average, restriction improved feed efficiency by 9%. Thus, the cheapest gains were made by the restricted barrows and the most expensive ones by the *ad libitum* fed gilts. Days required by the growing-finishing pigs from



Legend

- ● Ad-lib fed barrows
- ■ Ad-lib fed gilts
- o Restricted barrows
- □ Restricted gilts

Figure 4.4. Growth curves for pigs in experiment 6

20 to 90 kg were 91, 123, 133 and 136 for treatments A_4, B_4, C_4, and D , respectively. The *ad libitum* fed barrows reached market weight 40 days earlier than the average of the other three groups.

4.5.2 **Carcass characteristics and organ weights**

Plane of nutrition had no significant effect on the organs. Carcass characteristics were very significantly influenced by plane of nutrition. Plane of nutrition and sex had a significant interaction in percent empty body weight ($P < 0.05$), killing out percentage ($P < 0.01$) and backfat thickness ($P < 0.01$). Pigs in treatment A_4 had a significantly higher percentage of empty body weight than B_4 pigs ($P < 0.01$) and a higher killing out percentage than B_4 pigs ($P < 0.01$) and C_4 pigs ($P < 0.05$). They also had significantly shorter carcasses than B_4 and C_4 pigs ($P < 0.05$),as well as higher backfat thickness values than B_4, C_4 and D_4 pigs ($P < 0.01$). The weight of gut (with contents) was significantly lower in A_4 and C_4 than in B_4 pigs ($P < 0.01$).

Barrows tended to have lower gut weights and gut fill, more kidney fat, thicker backfat, shorter carcasses and higher killing out percentages than gilts.

Table 4.16 : Carcass characteristics and organ weights of pigs in experiment 6

Item	Treatment A_4	B_4	C_4	D_4	SE mean	CV %
Empty body weight, %	80.0^{a}	78.2^{b}	78.9^{ab}	79.2^{ab}	0.32	1.3
Killing out percentage	73.0^{a}	70.9^{b}	71.4^{b}	72.1^{ab}	0.39	1.6
Weight of kidney fat, g	796	721	725	721	34.0	16.2
Carcass length, cm	90.0^{a}	92.8^{ab}	93.9^{b}	93.8^{b}	0.86	3.2
Backfat thickness, mm	39^{a}	33^{b}	33^{b}	35^{b}	0.9	7.2
Weight of kidney, g	112	116	116	112	2.6	8.2
Weight of heart, g	250	267	232	261	7.7	9.9
Weight of liver, g	1612	1617	1629	1592	32.5	7.3
Weight of spleen, g	143	149	137	139	6.0	15.5
GITF, kg	8.1^{a}	9.5^{b}	8.3^{a}	8.6^{ab}	0.24	8.3
GITE; kg	4.2	4.5	4.3	4.6	0.18	14.3
GIT fill, kg	3.9	4.9	3.9	4.1	0.28	22.9

GITF = Gastrointestinal tract full. GITE = Gastrointestinal tract empty

GIT = Gastrointestinal tract

a, b = values in the rows bearing different superscripts are significantly different ($P < 0.05$).

CHAPTER 5

DISCUSSION

5.1 Chemical composition of cassava

Peeled cassava tubers were found to contain approximately 35% dry matter. Similar values were reported by Kakala (1981). Most researchers have reported values of 32% dry matter (Oyenuga, 1955; Jalaludin, 1977). Raymond et al. (1941) obtained quite a wide range of DM values from 100 varieties of cassava in Tanzania and documented an average value of 38%. Although Gomez (1977) has documented a range of 30 to 36% dry matter, it seems that there is a considerable variation, depending on age of roots and season of harvesting. It is possible that cassava harvested during the dry season in dry areas of the tropics may contain more dry matter than cassava harvested in the humid tropics. Oyenuga (1955) reported values of 28% to 32% for Nigerian varieties. In the present experiment, cassava harvested during the dry season was found to have higher dry matter than cassava harvested during the wet season.

The dry matter content in cassava root meal was found to be relatively high (89 to 97%) compared to values from other parts of the world, probably due to differences in temperature and relative humidity. Eggum and Kategile (1981) obtained values from 97 to 98% for Tanzanian Mzungu variety cassava. Most workers have obtained values ranging from 86 to 90% dry matter (Hutagalung et al., 1973; Hansen and Sunesen, 1973; Muller et al., 1975; Gomez, 1977; Sonaiya et al., 1982; Gomez et al., 1983).

The content of protein in cassava is low. Figures of 1.73 to 3.25 obtained in the present work are similar to values documented by other workers (Hansen and Sunesen, 1973; Muller et al., 1975; Jalaludin, 1977; Wyllie and Lekule, 1980; Just et al., 1983a; Ravindran et al., 1983a; Gomez et al., 1983). Some of the values are reported on a dry matter basis, while others are based on air-dried cassava, thus leading to slight variations in figures for protein contents. Cassava is, thus, deficient in protein, a condition which is worsened by the fact that 40 to 60% of the total nitrogen is probably in the form of non-protein-nitrogen (NPN) (Pond and Maner, 1974). The authors have pointed out that agronomic and genetic manipulation to increase protein contents seem to be limited. However, Jalaludin (1977) reported that through manipulation a new Colombia cultivar 'Llanera' with 7.25% protein had been developed.

The amino acid content compares very unfavourably with that of cereals or cereals by-products (Table 4.2). Muller et al. (1975) and Ravindran et al. (1983b) compared cassava with maize and found that cassava was very inferior in amino acid contents. Close et al. (1953), Hutagalung et al. (1973), Montaldo (1977), Hutagalung (1977), Wyllie and Lekule (1980), Eggum and Kategile (1981) and Just et al. (1983a) have shown a great variation in amino acid composition but contents are consistently low.

The NFE content in this study was very high at 90 to 94% and so was starch at 81 to 88%. This is due to the low crude fibre and ash content in the peeled cassava. The unpeeled cassava contained more crude fibre and ash and less NFE, while peels had very little

NFE. The degree of contamination with soil will also influence NFE values. Similar high values of NFE in cassava have been reported by Oyenuga (1955), Hutagalung et al. (1973), Wyllie and Lekule (1980) and Ravindran et al. (1983b). Values of less than 80% have been documented by Muller et al. (1975), Gomez (1977), Walker (1983) and Sonaiya et al. (1983). Hansen and Sunesen (1973) have summarized the results of various workers using cassava from different countries. The range of NFE is 73.0 to 81.5%, with most of the values being 80%. Many other workers have reported values ranging from 80 to 89% (Jalaludin, 1977; Sonaiya and Omole, 1983;Just et al., 1983a; Ravindran et al., 1983b). Some of the variation is due to the differences in the method and extent of processing and moisture content. Most of the workers have expressed the NFE or starch content on an air-dried basis. Thus, when expressed on a dry matter basis, it seems that well-prepared cassava root meal from peeled tubers contains about 90% NFE. Cassava root meal is, thus, very rich in starch and hence in energy.

The peels had higher contents of nitrogen, crude fibre (or NDF) and ash and were poor in starch (Table 4.1). Similar values were obtained by Oyenuga (1955) and Sonaiya and Omole (1977).

The mineral composition is not consistent and shows marked differences between laboratories in respect of Ca and P contents. Values obtained from the laboratory at the National Institute of Animal Science, Denmark, are close to values obtained earlier by Raymond et al. (1941) and Wyllie and Lekule (1980) for Tanzanian cassava varieties. Hutagalung (1977) reported a range of 0.04 to

0.35% calcium and 0.04 to 0.4% phosphorus. Thus, mineral composition seems to vary widely in cassava roots. On the basis of the analyses, cassava seems to be poor in calcium and phosphorus.

The chemical composition of cassava will thus depend on soil conditions, nature and extent of processing, age, variety and extent of contamination. Peeled cassava with no soil contamination seems to be fairly similar in crude protein, crude fibre, ash, ether extract and NFE contents but varies widely in mineral composition. Analyses of 145 samples in U K from 1981 to 1982 revealed similar composition of crude protein, crude fibre and ether extract as obtained in the present study, but values for starch were lower and those for ash higher.

5.2 Nitrogen balance of pigs fed cassava based diets

As the amount of nitrogen intake or digested increased, average daily gain generally increased. Nitrogen retention was, however, not highly correlated to daily gains or nitrogen intake. The coefficients of variance were high. Errors in nitrogen balance arise from collection, storage and preparation of faeces and urine samples for chemical analysis. During the study, temperatures ranged from 25 to 30^{o}C. As a result, the dry matter content of faeces at the time of collection was 48% with some values above 60%. By frequent collections the DM of faeces was reduced to 34%. Two samples of urine were used for nitrogen determination. Some of the values showed variations of 30% or more. These were rejected. Thus under the present conditions, the value of nitrogen balance studies is limited and must be treated with suspicion. Values obtained by Balogun and Fetuga (1984) were higher than the present values.

5.3 Digestibility of cassava based diets

Diets containing different proportions of maize and cassava had similar digestibility as well as metabolizable energy. The values obtained were similar to values reported by Hew and Hutagalung (1977) and Gomez and Valdivieso (1983). The latter authors concluded that cassava meal based diets improved digestibility in respect of crude protein.

When diets based on peeled and soaked cassava, peeled and sundried cassava were compared to a standard (commercial) diet and a diet based on rice polishings, interesting results were obtained. The rice polishing diet had a higher digestibility and ME content (16.1 MJ ME/kg DM) than the other diets (79 - 85% and 13.7 to 15.5 MJ). The CRT diet was more digestible than the CRM diet, probably due to higher fat (5.73 versus 2.47 %) and protein contents in the CRT diet. The differences were very marked for crude protein and crude fibre. Sonaiya and Omole (1982) found that cassava diets had a higher digestibility of dry matter and energy than sorghum diets. However, the coefficients of digestibility were much lower than the ones obtained in this study but similar to those obtained by Kakala (1981) while Gomez and Valdivieso (1983) recorded comparable values. Aumaitre (1967) also obtained higher digestibility of energy in cassava than in barley. The slightly lower digestibility of the control diet can be explained by the higher crude fibre and ash contents. The negative effects of crude fibre on digestibility have been clearly demonstrated by Just (1982a, b, c) and Just et al. (1983b). However, it was surprising to note that the CRT diet had a higher digestibility than the CRM diet.

The high digestibility of cassava based diets has been suggested by Gomez and Valdivieso (1983) to be a consequence of the physico-chemical characteristics of cassava starch; a small diameter starch granule, a low amylose content, and an X-ray diffraction pattern of the A-type are factors which facilitate an efficient amylolytic degradation of starch.

5.4 Effect of substituting cassava for maize in pig rations on growth, feed intake and feed efficiency

In the present study pigs fed maize diets performed poorly probably due to the toxicity of the stored kapok cake. This was unexpected and rather paradoxical. Results are contradictory to those of Hew and Hutagalung (1972) who showed that maize diets were superior to cassava diets. Daily gains and feed/gain ratios were 614 g and 3.76, 386 g and 5.05 for maize and cassava fed pigs respectively. It would thus be erroneous to conclude that cassava is superior to maize. Muller et al. (1972) found that maize (61.5%) and cassava (38%) diets both containing 0.65% lysine and 0.42% SAA, gave similar liveweight gain (441 and 439 g) and feed conversion (4.6 and 4.8). This is mainly associated with the level of animal protein in such diets. Some workers have observed better performance with control diets when animal protein was kept constant (Hew and Hutagalung, 1972; Gomez et al., 1977) while others have found better or equal performance of cassava diets with higher animal proteins (Maner and Gomez, 1973; Hew and Hutagalung, 1977; Khajarern et al., 1980c) or soybean meal (Khajarern et al., 1980b).

The poor performance and loss of body weight of pigs in these exeperiments were suspected to be due to kapok cake, although initially the possiblility of aflatoxicosis in the maize could not be discounted. Khajarern et al. (1980b) observed deaths after 12 weeks of feeding diets containing 79% maize, and, on autopsy, liver hypertrophy and excessive fatty tissue were revealed. The maize was found to be contaminated with aflatoxins. This possibility was ruled out in the present study due to the non-specificity of the symptoms in relation to cassava and maize inclusion in the diets and the fact that the maize used was newly harvested for human food. The fact that cassava is deficient in protein relative to maize implies that more proteins have to be included in cassava diets to correct this deficiency. Good quality proteins are not readily available in Tanzania at reasonable prices. Inclusion of kapok cake in rations was intended to limit the amount of cottonseed cake because of its well-known toxic gossypol content. The diarrhoea observed, impaired feed intake and growth, hind quarter incoordination, dwarfism, excessive fat and fat necrosis in pigs fed diets containing kapok cake suggest that stored kapok cake may have serious toxicological effects on pigs.

Although fairly low levels of kapok cake were included after the first four weeks, the deterioration in the performance of the pigs, which had received high levels of kapok cake, suggests that these toxicological effects might be carry-over effects, and the toxicity is cumulative. This is probably the main reason for the poor performance and especially of the maize-based diets, as they had higher levels of kapok cake.

Kapok cake, which is produced mainly in East Africa, South East Asia and South America, has been the subject of very few studies. Siriwardene and Manamperi (1979), working in Sri Lanka, found that kapok cake in broiler diets decreased growth at 20% inclusion and caused a high mortality rate at a 30% inclusion in diets.

The results of the growth study are inconclusive in respect of relative nutritive value of cassava and maize. However, the digestibility study shows that cassava - based diets are highly digestible and are similar to maize diets. This is an indication that maize can probably be replaced by cassava in pig diets without affecting the nutritive value, provided the diets are well-balanced for protein and vitamins. Care should be taken in the use of kapok cake in pig diets.

5.5 Effect of different methods of processing cassava on performance of pigs

5.5.1 Feed intake, feed efficiency and growth rate

Cassava processed in two different ways, viz. peeling and soaking versus peeling and sundrying, was used to formulate diets, which were then compared with a standard (commercial) diet and a diet based on rice polishings, which is an important pig feed in Tanzania and widely used in areas close to industrial rice mills. Peeled fresh cassava was also compared with cassava root meal (experiment 5). The rice polishings used had high levels of amino acids compared to those of cassava and maize (Table 4.2). Relative to cassava, rice polishings require much less protein supplementation.

Feed intake and daily gains were very similar in all treatments. Pigs fed rice polishings had slightly higher daily gains and a better feed efficiency than the control group and the pigs fed cassava. These differences can be explained by the higher digestibility of the rice polishings diet, resulting in the highest ME content i.e. 16.1 MJ ME/kg DM. Pigs in this treatment had the highest daily intake of metabolizable energy. The higher amino acid content in rice polishings, and consequently in the diet based on this commodity, could also have improved protein digestibility and utilization. This diet completely fulfilled the NRC (1979) requirements of lysine and sulphur amino acids (SAA) for growing-finishing pigs, while the rest of the diets did not meet requirements of growing pigs.

In terms of ME/kg gain, the CRM pigs were the most efficient, and pigs in the other treatments had similar efficiencies, but differences are insignificant and hence of no account.

Sonaiya and Omole (1983) found that cassava diets had a higher digestibility of dry matter and energy than sorghum diets, but there were no differences in growth rate.

Feed intake was generally high when protein level was high (experiment 3) and was not depressed by the bulkiness of the fresh roots or the powdery nature of cassava root meal, contrary to observations by Khajarern et al. (1980b) and Tewe (1982), but in agreement with Gomez et al. (1983). However, these authors obtained higher gains and feed efficiency. This is in agreement with our results when the protein level was reduced (experiment 5). Feed intake and growth rate was reduced but feed efficiency was improved. Pigs fed fresh cassava had the lowest feed intake and gains. The lower feed intake observed in treatment A_3 could be due to inability of the relatively younger pigs to cope with the bulk or low palatability of fresh roots. It is possible that the residual hydrocyanic acid in the fresh cassava could reduce feed intake (Gomez, 1977).

As pointed out by Gomez (1977), consumption of fresh cassava depends on the protein content of the supplement and increases with increased protein levels and hence the higher feed intake in experiment 3 as compared to experiment 5. The differences can be explained by the differences in diet formulations, as shown by Gomez et al. (1984). In this latter study, feed intake and feed conversion ratio were lower while daily gains were similar, and for some diets lower than those obtained in the present study. Chou et al. (1973) found that diets containing up to 38% cassava roots were comparable to maize diets for liveweight gains and feed efficiency, but pigs on pelleted cassava performed better. The daily gains were lower than those obtained in this study, but feed efficiency was higher. The results of this study are not in agreement with those of Maner et al. (1967), Hew and Hutagalung (1972), Hutagalung et al. (1973) and Muller et al. (1975), who showed that an increase in the cassava root meal level in the diet (at the expense of maize) brings about a corresponding decrease in performance. Without methionine supplementation, liveweight gain and feed efficiency were lower. Muller et al. (1975) attributed the depression in growth rate to reduced palatability, when cassava is in excess of 30% of the diet. Tewe (1982) attributed the reduction in feed intake by young pigs fed cassava to the powdery nature of the feed as it may reduce palatability. Maner et al. (1967) have presented evidence that finishing pigs fed ad libitum will consume less when the diet contains 50% or more cassava.

Walker (1983) observed that in group-fed pigs, feed consumption increased steadily, and after one or two weeks the pigs were accustomed to cassava diets, but Gomez and Valdivieso (1983) found that piglets preferred diets containing the highest levels of cassava (up to 40%) relative to sorghum diets. Walker (1985) observed that despite similar feed intake and feed efficiency of pigs fed cassava and cereal diets, growth was reduced in pigs fed cassava.

The occurrence of loose faeces in the CRT diet group does not appear to influence performance of the pigs. Muller et al. (1972) attributed wetness of faeces to a lower amylase content in cassava. However, faeces from the CRM pigs were normal.

Job (1975) fed pigs fresh cassava and obtained similar liveweight gains as in this study, but the feed efficiency was higher. The author observed that as the level of protein in the protein mixture was increased, consumption of fresh cassava increased, while that of protein concentrate decreased and there was a fall in live weight. Control pigs had slightly lower gains and feed efficiency. Khajarern et al. (1980c) found that addition of fishmeal to cassava diets enhanced feed intake and growth rate.

The results of experiments on growth rate and feed intake are comparable to those of most other workers, but feed efficiency was lower. This could be attributed in part to the disease incidence and differences in protein supplements, particularly in the levels of lysine and methionine which were low in all but the rice polishings diet. The possible cause of the skin lesions is mineral deficiency especially Zinc as demonstrated by Maust et al. (1972) for cassava rice bran diets. The high levels of Calcium in the diets is a predisposing condition for Zinc deficiency and hence parakeratosis.

Diarrhoea observed in the first weeks of the experiment (expt. 5) was also reported by Hew and Hutagalung (1972) in a weaner study. The diarrhoea diminished gradually after several weeks as the pigs adapted to the diet. Growth was adversely affected (Fig. 4.3). The incidence of diarrhoea in young pigs has been observed by Hutagalung (1972), Maust et al. (1972), Arambawela et al. (1975) and Hansen et al. (1976), although Aumaitre (1967) observed the reverse. Hew and Hutagalung (1977) have suggested that scouring occurs if pigs are fed cassava high in HCN since HCN is a scouring contributing factor.

Since cassava fed in the CRT + CSC + SC treatment was fed fresh, it is most likely that levels of HCN were sufficiently high to cause diarrhoea in the youngest pigs. This finding tend to suggest that cassava, especially fresh, should not be introduced to young pigs of less than 20kg liveweight and only moderate amounts up to about 30 kg liveweight.

Stored cassava tubers, which had softened, were disliked by the pigs. Booth et al. (1976) have attributed this to textural, structural and organoleptic changes. These authors suggested that the softening may, in part, be caused by changes in moisture and starch content and quality, especially water holding capacity.

On the basis of feed conversion observed, a pig would require 406 kg of peeled, soaked cassava and 152 kg of protein concentrate from 20 to 90 kg liveweight. This experiment shows that cassava is an excellent source of energy for growing-finishing pigs. Further, it shows that cassava can be offered as a meal in mixed diets or separately as fresh (soaked) roots with a protein supplement. In both forms, cassava-based diets were comparable to the commercial sow and weaner meal or rice polishings diet in digestibility and in promoting live weight gain. Bulkiness of cassava tubers and dustiness of cassava root meal did not seem to influence feed intake.

5.5.2 Carcass characteristics

Carcass characterics were closely related to the content of crude fibre in the diet. As expected, the control pigs, which received the highest crude fibre, had the lowest empty body weight, longest large intestine, highest gut fill, and a slightly heavier gastrointestinal tract.

Pigs fed fresh cassava had the thinnest backfat and lower dressing percentage, while cassava diets resulted in the lowest kidney fat value and the rice polishings diet in the highest value. It is well-established that fat deposition increases with digestible energy intake, but the utilization (fat deposition) is reduced by increasing dietary crude fibre. The response of the pigs fed rice polishings is in agreement with this phenomenon, but not that of pigs on cassava diets. Thus, in spite of the similarity in live weight gains, pigs fed cassava seem to have deposited less fat. It is possible that the utilization of ME in cassava is lower than that from cereals (Walker, 1983) or their by-products, because fat deposition requires more energy per kg than protein deposition (Williams et al., 1955). Walker (1983) observed that the utilization of ME in cassava was lower than that from control diets. Since cassava contains a high proportion of amylopectin, Oke (1978) has argued that this may increase the quantity of undigested carbohydrate reaching the large intestine, and it may lead to poor utilization of ME (Just et al., 1983b).

Partridge (1985) found that there was a larger proportion of starch from cassava digested in the hind gut, and according to Just et al. (1983b), each 1% increase in the proportion of energy disappearing in the hind gut decreases utilization of ME by 0.5%.

The results of the present study are in agreement with those of Sonaiya et al. (1982) who found that cassava did not significantly influence carcass characteristics, but the highest level of cassava produced leaner carcasses. Similarly, Babyegeya (1980) observed decreased backfat thicknesses and increased killing-out percentage with increased cassava levels in pig diets. Chicco et al. (1972), Chou and Muller (1972), Maner and Gomez (1973), Muller et al. (1974), Hew and Hutagalung (1977) and Wyllie and Lekule (1980) did not find any deleterious effects of dietary cassava on carcass characteristics.The opposite has been reported by Oyenuga and Opeke (1957), Hutagalung et al. (1973) and Walker (1983, 1985).

The results of gut measurements reflect the differences in crude fibre content in the diets. Digestion of fibre in the hind gut would tend to increase the proportion of hind gut and gut fill, when the fibre content in the diet is high (Jorgensen et al., 1985). The heavier thyroids observed for the control diet group suggest that this diet contained higher levels of goitrogenic substances than the other diets (Sihombing et al., 1974; Cromwell et al., 1975). This also suggests that the HCN levels in the cassava were sufficiently low not to have a goitrogenic effect.

It is apparent that the response of pigs to cassava diets will depend on the general composition of diets, protein supplements, level of cyanogenic glucosides in the cassava, and the level of feeding. From the results of the present study, it can be concluded that cassava is an efficient source of energy for pigs when levels of amino acids in the diet are optimal. Whether offered as a meal or soaked tubers, or fresh peeled tubers, feed intake, feed efficiency, growth rate, and carcass characteristics are not seriously affected. Cassava can satisfactorily replace all cereals in diets of growing-finishing pigs, provided the diets are optimized to meet nutritional requirements.

5.6 Effect of different protein supplements in cassava-based rations

The diets in this experiment had protein levels below the NRC (1979) recommendations. The amino acid content met only the requirements of finishing pigs. Balogun et al. (1983) found that the methionine + cystine requirements of pigs fed a cassava-flour-based diet were higher than 0.65%. This was suggested to be due to an additional requirement of methionine for other metabolic functions, possibly the diversion of methionine from its obligatory role of protein synthesis to one of detoxification of residual hydrocyanic acid in the cassava. Maximum growth rate, efficiency of liveweight gain, and nitrogen retention was observed when the diet contained 0.89% sulphur amino acids (SAA).

In a subsequent study, Balogun & Fetuga (1984) found 0.63% methionine in a diet containing 20% cassava to be adequate. Gomez

(1977) has recommended the use of methionine supplementation when high levels of cassava are mixed in composite diets with plant sources such as soyabean meal.

The pigs peeled the chopped cassava tubers before consuming them. They preferred the parenchymatous tissue to the peels. This is an indication that in the sweet varieties, the peels have higher HCN contents and are bitter (Coursey, 1973; CIAT, 1978). Booth et al. (1976) observed that some of the sweet cultivars exhibit a relatively high HCN content in their peels despite the relatively low content in the whole root. Peeling removes most of the cyanide in sweet varieties (Johnson and Raymond, 1965; Coursey, 1973).

5.6.1 Feed intake, feed efficiency and growth rate.

Feed intake, feed efficiency and growth rate were not significantly affected by the type of protein supplement. Job (1975) showed that pigs fed 30% protein concentrate consumed 2.74 kg fresh cassava and 1.00 kg protein concentrate. These results are in total agreement with the results of this experiment. However, Job (1975) obtained higher gains due to a better feed efficiency. Without restricting the protein supplement, Gomez (1977) obtained higher gains and a slightly better feed efficiency, compared to the present study, but the amount of cassava required to fatten a pig (390 - 400kg) was similar to the amount obtained in this experiment (383 kg).

Cottonseed cake (CSC) seems to offer a better protein source for cassava-fed pigs than sunflower cake (SC). Table 4.11. shows that cottonseed cake is superior to sunflower cake in amino acid composition except for methionine. Diet B_3 had the highest lysine content and its superiority in growth performance tends to support the argument that lysine is probably the most limiting amino acid in these cassava diets (Oke, 1978). However, the CRM + CSC diet also had the lowest crude fibre and ash. Hence, it is likely to be more digestible and has higher ME and is utilized better (Just, 1982a, b,c). All these attributes could explain the higher feed intake, feed efficiency and growth rate of pigs on that diet. In a comparison between cottonseed cake and other proteins in cassava based diets, Gomez et al. (1984) obtained similar liveweight gains.

Feed intake was higher than in this experiment, but feed efficiency was slightly lower. Like the diets in this experiments, the diets used by Gomez et al. (1984) were low in lysine and methionine. Nevertheless, methionine supplementation did not improve performance. It was noted that fishmeal improved performance of pigs fed cassava and cottonseed cake. Oke (1978) and Gomez et al. (1984) suggested that lysine rather than methionine could become of major importance in diets of this type. Maner (1973) obtained superior performance when soybean meal was used. When cottonseed cake constituted the protein supplement, average daily gain was 592 g, which is similar to results of this study. Feed consumption and feed efficiency were also similar.

In most of the experiments involving the use of cottonseed cake, amounts used were limited owing to the toxic gossypol in cottonseed cake. Gomez et al. (1984) satisfactorily used 33.7% and 26.1% cottonseed cake during the growing and finishing phases, respectively. Levels of up to 25% cottonseed cake have been included in our normal diets without deleterious effects. This level was also used in experiment 1. However, in commercial diets it is limited to 10% only. In experiments 3 and 6, ferrous sulphate was incorporated as a detoxicant. The high levels (40%) included in this experiment for growing-finishing pigs from 20 - 90 kg without harmful effects suggest that some of the cottonseed cake produced in Tanzania has low levels of gossypol and could be used at much higher levels than suggested in literature. This observation is of practical importance as cottonseed cake is plentiful and relatively cheap. Out of annual exports of 24,500 tons of oilcake, 21,000 tons were cottonseed cake (FAO, 1983). The maximum use of cottonseed cake in cassava diets is important because such diets require relatively large amounts of protein supplementation, and other or better protein sources are not easily obtainable, or the price and transportation costs may be prohibitive. Under these circumstances, cassava cannot be incorporated at levels higher than 60% without seriously limiting the protein content and, hence, that of essential amino acids.

5.6.2 Carcass characteristics.

Literature does not contain information on the effect on carcass characteristics following fresh cassava feeding. Kakala

(1981) observed a fall in the dressing percentage when cassava tubers and leaves were both incorporated in pig diets, but this was attributed to the higher crude fibre in cassava leaves. In the present experiment, pigs fed fresh cassava tended to have a higher gut fill and longer large and small intestines. Nevertheless, the weights, lengths and fill of the different parts of the gastrointestinal tract were very similar in the treatments with sunflower cake and were slightly higher than in the treatment with cottonseed cake only. This can be explained by the higher crude fibre content of sunflower cake. These effects have been well demonstrated by Just (1982a,b,c), Just et al. (1983a,b) and Jorgensen et al. (1985). Pigs fed sunflower cake had longer carcasses and almost similar backfat thickness, but slightly lower than in pigs fed cottonseed cake. Again, these differences are probably due to the higher crude fibre content in the sunflower cake.

It has been shown that cottonseed cake can probably be used at high levels of up to 40% of the diet without need for detoxification. It appears that the crude fibre content of protein sources has a considerable influence on performance and carcass characteristics of pigs and must be determined to assess the nutritive value of a feed. The experiment has shown that all pig farmers can use home-grown cassava with locally available protein supplements in rations for growing-finishing pigs. However, these diets should not be fed to weaners as they may trigger off diarrhoea.

5.7 Intake capacity of pigs of different sexes fed a standard cassava diet.

The diet used in this experiment was very similar to diets B_2 and B_3. Lysine contents meet NRC (1979) standards for finishing pigs, and the SAA are adequate for growing-finishing pigs.

In the preceding experiments there has been a marked sex difference in performance when pigs were group-fed ad libitum. Barrows had 20-30% higher growth rates than gilts. It was the objective of this experiment to determine whether the differences observed were due to differences in feed intake or efficiency of feed conversion or both, and to recommend suitable feeding regimes for cassava root meal diets, as well as to establish whether there is a need to separate the sexes at feeding.

5.7.1 Feed intake, feed efficiency and growth rate.

The marked differences shown in daily gains were closely related to feed intake. The cassava diet used here can be considered a low protein (14.6%) diet containing suboptimal levels of essential amino acids.

The results on feed intake, daily gain and feed conversion efficiency are very similar to those of previous experiments. They are in agreement with those of Khajarern et al. (1980b) on feed intake, but inferior on growth and feed efficiency. Sonaiya et al. (1982) observed much lower feed intakes and daily gains, while comparable results were obtained by Gomez et al. (1984) on liveweight gain, feed intake and feed efficiency.

Feed intake had the most marked effect on pig performance. This is evident from the differences between pigs on treatment A_4 and the other treatments. Initially, the ad lib. fed gilts had a higher feed intake and liveweight gain than gilts fed restrictedly, but feed intake was similar after five weeks. Compensatory effects in growth rate, feed intake and feed efficiency may play a part in this. Compensatory growth can be caused by increased feed intake and/or improved feed efficiency (Prince et al., 1983). This is likely to be the case during the adaptation period and the period shortly after, despite observations by some workers that cassava reduces ration palatability (Maner et al., 1967; Muller et al., 1975; Tewe, 1982) or requires an adaptation period (Maner et al., 1976; Walker, 1983). The results of Donker et al., (1986) are similar to those of this experiment. Pigs fed ad lib. and pigs allowed feed for 4 hr/day had daily gain, feed intake and feed conversion ratios of 709 g, 2307g, 3.27 and 616 g, 1944 g, 3.16, respectively. The faster growth was due to higher feed intake. Other workers have obtained similar results (Arambawela et al., (1975). Passback et al. (1968) observed a reduction in feed efficiency following reduced feed intake.

Differences between sexes in ad libitum feed intake are well-known, especially the differences between barrows and gilts (Campbell and King, 1982; Just et al., 1985). In the present study, barrows had a higher feed intake, daily gain and feed efficiency. These results are in agreement with those of Castell *et al*. (1985) and Donker *et al*. (1986), but the latter authors did not find any differences in feed efficiency. Just *et al*. (1985) obtained similar results for feed intake and liveweight gain, although, in their case, the differences were very small. However, gilts were more efficient than barrows. It is possible that when less palatable diets such as cassava-based diets are fed, differences in feed intake between barrows and gilts will increase.

There was a significant interaction between level of feeding and sex on average daily gain and feed conversion ratios. Similar observations were made by Campbell and King (1982), but Donker *et al*. (1986) did not find any interaction. Very contrasting results were obtained by Fuller and Livingstone (1978). At different degrees of restriction, gilts grew faster and had a higher efficiency of feed conversion, and the differences increased with restriction. In the present study, restricted barrows grew faster and had a higher efficiency of feed conversion than gilts. These results are in agreement with those of Hale and Southwell (1967) but are contradicted by those of Perez and Desmoulin (1976) who observed no differences in feed intake or daily gains. The results of this experiment confirm the results of Lekule *et al.* (1982) showing that at the same feed intake in a restricted regime barrows had a higher feed efficiency and growth rate than gilts.

Barrows fed *ad libitum* had a higher fat deposition, as indicated by the higher backfat thickness and heavier kidney fat. However, the efficiency of feed utilization was not significantly different from that of the other groups. Thus, in the *ad lib.* fed barrows, the energy saved by faster growth, which then reduced maintenance requirements, counterbalanced the extra energy required for fat deposition. The restricted barrows, which had similar backfat thickness and kidney fat as the gilts, showed an even higher feed efficiency. Just *et al.* (1985) have demonstrated that barrows have a higher efficiency of fat deposition but a lower protein deposition than gilts.

5.7.2 Carcass characteristics.

The effects of plane of nutrition and sex on carcass characteristics have been determined by Just (1973), Just *et al.* (1983b) and Donker *et al.* (1986). As in the case of growth performance, the level of feed intake had the greatest influence on carcass characteristics, and, in some cases, the interaction between feed intake and sex was significant. Due to a much lower feed intake in the *ad lib.* fed gilts, which was comparable to the restricted gilts, both groups can be considered as having been on a high plane of nutrition. Thus, the high feed intake in barrows induced a higher dressing percentage, shorter carcass and thicker backfat. Similar results were obtained by Passback *et al.* (1968), Fuller and Livingstone (1978) and Donker *et al.* (1986).

The slightly lower gut fill and weight of gut observed in barrows is contrary to observations by Just *et al.* (1985) and Donker *et al.* (1986), as well as results of experiment 5, but are in agreement with results of experiment 3. Since the restricted pigs did not differ significantly in carcass characteristics, it seems that on the same level of feed intake there are no differences between sexes. Carcass quality is a relative term in Tanzania. What may appear as a low quality carcass by a certain group of consumers may be regarded as a first-class carcass by another one or in a different location. Preference for fat or lean carcasses in any locality depends on the availability and price of vegetable oils relative to lard, personal income, religion (Islam), and traditions. At present the demand for fat carcasses is high in the rural areas, and the trimmed lard fetches a higher price than the lean meat. In urban centres, the situation is not very clear. Since grass and very bulky feeds form the main diets for pigs, it is relatively difficult to get very fat carcasses during the growing-finishing period, and pigs have to be carried to very heavy weights. A high plane of nutrition would, thus, have two effects, viz. high growth rate and relatively fatter carcasses at lighter weights. For this former reason, a high feed intake is a very desirable trait in pigs. In the long term, production of lean meat should be the prime objective, as good quality protein is lacking in human diets, and energy can be produced more cheaply from other sources.

This experiment has further confirmed that cassava supports good performance in growing-finishing pigs. Barrows have a higher feed intake than gilts and, hence, a higher feed allowance is required to promote faster growth in barrows. It can be concluded that special attention should be paid to optimal feeding levels in relation to the feed intake capacity of the pigs.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the experiments conducted to study the nutritive value of cassava:

1. Sweet varieties of cassava can be fed fresh to pigs either peeled or unpeeled. Further, they can be soaked in water for about two days prior to being fed to reduce the HCN levels. About 390 to 406 kg of peeled cassava and 112 to 152 kg protein supplement (25 - 35%% CP) are required to raise a pig from 20 to 90 kg. Cassava root tubers can be fed unpeeled, as pigs will effectively peel them. Assuming that peels comprise 20% of the tubers about 500 kg of unpeeled cassava will be required to fatten one pig. With a yield of 10 t/ha of fresh tubers, a farmer could raise 20 pigs on a hectare of cassava. This could have a great impact on cassava production and utilization as well as on the subsistence economy of peasant farmers.

2. Cassava, either fresh or as a meal, can almost fully replace cereals in pig diets without affecting performance, provided such diets are well balanced for protein, vitamin and minerals.

Cassava is proposed to have the following average chemical composition (% of dry matter):

	Peeled fresh cassava	Peeled dry cassava	Cassava peels
Dry matter	35	92	93
Crude protein	2.4	2.4	5.4
Crude fibre	3.2	3.2	5.0
Ether extract	0.7	0.7	1.3
Ash	2.4	2.4	5.8
NFE	92.0	92.0	-
DE Mcal/kg DM	3.9	3.9	3.5
Digestibility	80	80	

3. Cassava seems to incite gastro-intestinal disturbances in young pigs below 20 kg liveweight. Cassava is not recommended for such young pigs.

4. Sweet varieties of cassava grown in Tanzania seem to have non-toxic levels of cyanogenic glucosides and are palatable to the extent of not affecting feed intake when they completely replace cereals in pig diets.

5. Cottonseed cake can be used as the main protein source in cassava - based diets under Tanzania conditions. Levels of up to 40% inclusion did not produce toxic or deleterious effects in growing - finishing pigs.

6. The maximum inclusion of cassava in pig diets will depend on the potential level of HCN, price of cassava relative to that of other energy sources available, availability and price of protein supplements, and the class of pigs to be fed such diets.

In Tanzania, cassava is not normally used in commercial livestock feeds for reasons outlined earlier. As long as the feed mills strive to produce the best feeds using mainly maize, the use of cassava in commercial rations will not be realised in the near future.

The failure by researchers and policy makers to promote the use of cassava in livestock feeds represents omission to utilize a crop, which can be produced cheaply in almost all parts of Tanzania. The potential of cassava is very high, but it will not be realised, if alternative uses of the crop as for example in livestock feeds will not be encouraged in the spirit of self-reliance. Although the pig is in the shadow of cattle in Tanzania, it has a role to play, especially in peri-urban agriculture and in some rural communities. It will not be too long, before the supply of cereal by-products becomes a serious limitation to pig production. The increasing demand for pork, especially in urban centres, has changed backyard pig raising into big business.

The use of cassava for pig feeding by peasant farmers would enable these farmers to keep more pigs in the village. This would increase earnings, create a local demand for cassava and improve the nutritional status of the farmers. The study has demonstrated that cassava is a good source of energy for pigs, but before a well-founded recommendation can be made, the following questions need to be answered:

1. How much cassava can be used in weaner diets without causing gastro-intestinal disturbances?
2. What is the long-term effect of cassava diets on the reproductive performance of breeding pigs?
3. How much HCN is removed by different processing methods in sweet and bitter varieties.
4. Does the present price of cassava reflect cost of production in relation to production of cereals? Will production of commercial livestock/pig feeds based on cassava be economical?

The following are recommendations:

1. A multidisciplinary research effort is required to solve the above problems.
2. Further studies are required to examine the gossypol levels of cottonseed cake and to ascertain safety values for its inclusion in pigs diets.
3. A deliberate effort is required to encourage the use of cassava in pig diets in the rural areas.
4. The present dealienation of the rural livestock producer from the peri-urban producer, whereby the commercial feed mills try to produce the best feeds from cereals for the peri-urban

producer, is unhealthy and has a long-term negative effect on livestock production. This is very much the case in Tanzania, where livestock production is basically in the hands of rural peasant farmers. Feed mills should be encouraged to meet demands of rural producers also by producing more feeds, which are relatively cheap, albeit suboptimal for high production, using raw materials with a lower competitive value as human food.

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APPENDIX 1.

Chemical composition of faeces in experiment 2. (DM basis)

Treat-ment	Period	DM	OM	CP	CF	EE	Ash	NFE
A_1	1	95.05	88.13	23.20	20.98	6.64	11.87	37.31
	2	99.85	85.10	15.05	23.91	5.94	14.90	40.20
	3	97.67	84.90	16.99	23.52	6.24	15.10	38.15
	4	92.45	85.43	18.46	21.65	6.99	14.57	38.33
B_1	1	94.72	84.39	25.78	25.08	6.38	15.61	27.15
	2	97.74	86.93	19.71	23.11	5.64	13.07	38.47
	3	96.35	85.96	17.36	21.23	6.12	14.04	41.25
	4	93.47	81.04	16.88	22.52	5.47	18.96	36.17
C_1	1	99.52	85.62	18.09	24.54	3.02	14.38	39.97
	2	98.96	82.51	17.20	22.97	2.24	17.49	40.10
	3	94.33	80.54	18.28	24.67	4.28	19.46	33.31
	4	91.50	82.83	19.88	24.16	3.06	17.17	35.73
D_1	1	98.94	86.11	19.87	27.95	3.25	13.89	35.04
	2	96.97	87.56	20.24	26.41	4.03	12.44	36.88
	3	94.01	86.78	13.71	25.30	2.98	13,22	44.79
	4	95.78	83.48	23.89	27.14	3.38	16.52	29.07

DM = Dry matter.
OM = Organic matter
CP = Crude protein
CF = Crude fibre
EE = Ether extractives
NFE = Nitrogen-free extract

APPENDIX 2

Digestibility of diet A_1 in experiment 2

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	6601	6249.8	1147.3	427.7	412.6	351.2	4262.3
Feed in faeces, g	1399.4	1233.3	324.7	293.6	92.9	166.1	522.1
Feed digested, g	520.6	5016.5	822.6	134.1	319.7	185.1	3740.2
Dig. coeff., %	78.80	80.27	71.70	31.35	77.48	52.71	87.75
2.							
Feed intake, g	9241.4	8749.8	1606.2	598.8	577.6	491.6	5967.2
Feed in faeces, g	1969.14	1675,7	296.4	470.8	117.0	293.4	791.6
Feed digested, g	7272.3	7074.1	1309.8	128.0	460.6	198.2	5175,6
Dig. coeff., %	78.69	80.85	81.55	21.38	79.74	40.32	86.73
3.							
Feed intake, g	10561.6	9999.7	1835.6	684.4	660.1	561.9	6819.6
Feed in faeces, g	2541.6	2157,8	431.8	597,8	158.6	383.8	969,6
Feed digested, g	8020.0	7841.9	1403.8	86.6	501.5	178.1	5850.0
Dig. coeff., %	75,94	78.42	76,48	12.65	75.97	31.70	85.78
4,							
Feed intake, g	11881.8	11249.7	2065.1	769.9	742.6	632.1	7672.1
Feed in faeces, g	2315.0	1977,7	427,3	501.2	161.8	337.3	887.3
Feed digested, g	9566.9	9272.0	1637.8	268.7	580.8	294.8	6784.8
Dig. coeff., %	80,52	82.42	79.31	34.90	78.21	46.64	88.43
Mean	78.49	80.49	77.26	25.07	77.85	42.84	87.17

APPENDIX 3

Digestibility of diet B_1 in experiment 2

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	6508.6	6169.5	1054.4	413.9	378.1	339.1	4323.0
Feed in faeces, g	1156.7	976.1	298.2	290.1	73.8	180.6	314.0
Feed digested, g	5351.9	5193.4	756.2	123.8	304.3	158.5	4009.0
Dig. coeff., %	82.23	84.18	71.72	29.91	80.48	46.74	92.74
2.							
Feed intake, g	9112.0	8637.3	1476.1	579.5	529.4	474.7	6052.2
Feed in faeces, g	1764.7	1534.1	347.8	407.8	99.5	230.6	678.9
Feed digested, g	7347.3	7103.2	1128.3	171.7	429.9	244.1	5373.3
Dig. coeff., %	80.63	82.24	76.43	29.63	81.21	51.42	88.78
3.							
Feed intake, g	7438.4	7053.1	1202.0	489.4	407.6	385.3	4921.2
Feed in faeces, g	1659.6	1426.6	288.1	352.3	101.6	233.0	684.6
Feed digested, g	5778.8	5626.5	913.9	137.1	306.0	152.3	4236.6
Dig. coeff., %	77.69	79.77	76.03	28.01	75.07	39.53	86.09
4.							
Feed intake, g	11715.5	11121.5	1969.4	1042.7	591.6	594.0	7517.8
Feed in faeces, g	2336.1	1893.2	394.3	526.1	127.8	442.9	845.0
Feed digested, g	9378.9	9228.3	1575.1	516.6	463.8	151.1	6672.8
Dig. coeff., %	80.08	82.98	79.98	49.54	78.40	25.44	88.76
Mean	80.15	82.29	76.04	34.27	78.79	40.78	89.09

APPENDIX 4

Digestibility of diet C_1 in experiment 2

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	6451.2	6117.0	1042.5	424.5	353.5	334.2	4268.1
Feed in faeces, g	1355.2	1160.3	245.2	332.6	40.9	194.9	541.7
Feed digested, g	5059.0	4956.7	797.3	91.9	312.6	139.3	3726.4
Dig. coeff., %	78.99	81.03	76.48	21.65	88.43	41.68	87.31
2.							
Feed intake, g	9031.7	8563.9	1459.5	594.3	494.9	467.8	5975.4
Feed in faeces, g	1897.4	1565.5	326.4	435.8	42.5	331.9	760.9
Feed digested, g	7134.3	6998.4	1133.1	158.5	452.4	135.9	5214.5
Dig. coeff., %	78.99	81.72	77.64	26.67	91.41	29.05	87.27
3.							
Feed intake, g	10321.9	9787.2	1668.0	679.2	565.6	534.7	6829.0
Feed in faeces, g	2193.7	1766.8	401.0	541.2	93.9	426.9	730.7
Feed digested, g	8128.2	8020.4	1267.0	138.0	471.7	107.8	6098.3
Dig. coeff., %	78.75	81.95	75.96	20.32	83.40	20.16	89.30
4.							
Feed intake, g	11612.2	11010.7	1876.5	764.1	636.3	601.5	7682.6
Feed in faeces, g	2283.7	1891.6	454.0	551.7	69.9	392.1	816.0
Feed digested, g	9328.5	9119.1	1422.5	212.4	566.4	209.4	6866.6
Dig. coeff., %	80.33	82.82	75.80	27.80	89.01	34.81	89.38
Mean	79.27	81.88	76.47	24.11	88.06	31.43	88.32

APPENDIX 5

Digestibility of diet D_1 in experiment 2

Periods	DM	O M	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	6451.9	6124.8	1084.6	574.2	325.8	327.1	4140.2
Feed in faeces, g	1296.4	1116.3	257.6	362.3	42.1	180.1	454.3
Feed digested, g	5155.5	5008.5	827.0	211.9	283.7	147.0	3685.9
Dig. coeff., %	79.91	81.77	76.25	36.90	87.08	44.94	89.03
2.							
Feed intake, g	9032.7	8574.7	1518.4	803.9	456.2	458.0	5796.3
Feed in faeces, g	1987.1	1739.9	402.2	524.8	80.1	247.2	732.8
Feed digested, g	7045.6	6834.8	1116.2	279.1	376.1	210.8	5063.5
Dig. coeff., %	78.00	79.71	73.51	34.72	82.44	46.03	87.36
3.							
Feed intake, g	10323.0	9799.6	1735.3	918.7	521.3	523.4	6624.3
Feed in faeces, g	2194.6	1904.5	300.9	555.2	65.4	290.1	983.0
Feed digested, g	8128.4	7895.1	1434.4	363.5	455.9	233.3	5641.3
Dig. coeff., %	78.74	80.57	82.66	39.57	87.45	44.57	85.16
4.							
Feed intake, g	11613.4	11024.6	1952.2	1033.6	586.5	588.8	7452.3
Feed in faeces, g	2330.0	1945.1	556.6	632.4	78.8	384.9	677.3
Feed digested, g	9283.4	9079.5	1395.6	401.2	507.7	203.9	6775.0
Dig. coeff., %	79.94	82.36	71.49	38.82	86.56	34.63	90.91
Mean	79.15	81.10	75.98	37.50	85.88	42.54	88.12

APPENDIX 6

Urine and urinary N output in experiment 2.

Diet	Pig No.	Total urine, g	Urine g/day	% N	g N/day
A_1	57	9440	1348.57	0.78	10.52
	53	9627	1375.29	1.44	19.80
	57	12958	1851.14	0.91	16.85
	53	16176	2310.86	0.65	15.02
B_1	53	6080	868.57	1.42	12.34
	57	9260	1322.86	1.27	16.80
	53	10726	1532.29	1.20	18.39
	57	15851	2264.43	1.06	24.00
C_1	57	8600	1228.57	0.92	11.30
	53	9831	1404.43	1.04	14.61
	57	12157	1736.71	0.72	12.50
	53	14659	2094.14	0.90	18.85
D_1	53	7940	1134.29	1.09	12.36
	57	9384	1340.57	1.20	16.09
	53	13524	1932.00	1.01	19.51
	57	15084	2154.86	1.19	25.64

APPENDIX 7

Nitrogen input in feed and nitrogen output in faeces in experiment 2.

Diet	Pig No.	Feed g/day	% CP	% N	g N consumed per day	Faecal output/ day, g	% CP	Total CP, g	g N/ day
		FEED				FAECES			
A_1	57	1000	15.69	2.51	25.1	477.1	9.72	46.37	7.42
	53	1400	15.69	2.51	35.1	754.2	8.52	64.26	10.28
	57	1600	15.69	2.51	40.2	867.1	7.12	61.74	9.88
	53	1800	15.69	2.51	45.2	982.6	7.81	76.74	12.28
B_1	53	1000	14.61	2.34	23.4	527.9	8.07	42.60	6.82
	57	1400	14.61	2.34	32.8	561.6	8.85	49.70	7.95
	53[1]	1600	14.61	2.34	37.4	767.6	7.50	57.57	11.51
	57	1800	14.61	2.34	42.1	910.3	6.75	61.43	8.78
C_1	57	1000	14.50	2.32	23.2	425.9	8.23	35.05	5.01
	53	1400	14.50	2.32	32.5	533.7	8.74	46.65	7.46
	57	1600	14.50	2.32	37.1	817.6	7.00	57.23	9.16
	53	1800	14.50	2.32	41.8	791.4	8.19	64.82	10.37
D_1	53	1000	15.41	2.47	24.7	301.7	12.20	36.81	5.26
	57	1400	15.41	2.47	35.6	569.4	10.10	57.51	8.22
	53	1600	15.41	2.47	39.5	625.7	8.75	54.75	8.76
	57	1800	15.41	2.47	44.5	752.7	10.56	79.49	11.36

1 Pig No. 53 developed diarrhoea on the sixth day of the collection period.

APPENDIX 8

Nitrogen balance in experiment 2

Diet	Pig No.	g N in feed	g N in faeces	g N in urine	N-balance, g
A_1	57	25.1	7.4	10.5	+ 7.2
	53	35-1	10.3	19.8	+ 5.0
	57	40.2	9.9	16.9	+ 13.4
	53	45.2	12.3	15.0	+ 17.9
B_1	53	23.4	6.8	12.3	+ 4.3
	57	32.8	8.0	16.8	+ 8.0
	53	37.4	11.5	18.4	+ 7.5
	57	42.1	8.8	24.0	+ 9.3
C_1	57	23.2	5.0	11.3	+ 6.9
	53	32.5	7.5	14.6	+ 10,4
	57	37.1	9,2	12.5	+ 15.4
	53	41.8	10.4	18.9	+ 12.5
D_1	53	24.7	5,3	12.4	+ 7.0
	57	35.6	8.2	16.1	+ 11.3
	53	39.5	8.8	19.5	+ 11.2
	57	44.5	11.4	25.6	+ 7.5

APPENDIX 9

Nitrogen retention in experiment 2

Diet	Pig No.	g N consumed per day	Faecal N per day	Dig. N per day	N retention % of intake	N retention % of digested	Av. daily gain, g
A_1	57	25.1	7.4	17.7	28.7	40.7	143
	53	35.1	10.3	24.8	14.2	20.2	71
	57	40.2	9.9	30.3	33.3	44.2	429
	53	45.2	12.3	30.2	39.6	59.3	500
Means					29.0	41.1	286
B_1	53	23.4	6.8	16.6	18.4	25.9	167
	57	32.8	8.0	24.8	24.4	32.3	257
	53	37.4	11.5	25.9	20.0	29.0	286
	57	42.1	8.8	33.3	22.1	27.9	286
Means					21.2	28.8	249
C_1	57	23.2	5.0	18.2	29.7	37.9	300
	53	32.5	7.5	25.0	32.0	41.6	333
	57	37.1	9.2	27.9	41.5	55.2	417
	53	41.8	10.4	31.4	29.9	39.8	517
Means					33.3	43.6	392
D_1	53	24.7	5.3	19.4	28.3	36.1	250
	57	35.6	8.2	27.4	31.7	41.2	271
	53	39.5	8.8	30.7	28.4	36.5	583
	57	44.5	11.4	33.1	16.9	21.8	429
Means					26.3	33.9	383

APPENDIX 10

Differences between means in experiment 3

Item	Level of significance		
Per cent empty body weight	A_2-B_2** A_2-C_2* A_2-D_2***		
Weight of kidney fat		B_2-D_2*	C_2-D_2**
Weight of liver	A_2-B_2*	B_2-C_2* B_2-D_2**	
Weight of thyroid	A_2-B_2* A_2-C_2** A_2-D_2**		
Gastrointestinal tract, full	A_2-D_2*		
Small intestine, empty	A_2-B_2* A_2-D_2**		
Large intestine, full	A_2-B_2** A_2-D_2**	B_2-C_2*	C_2-D_2*
Large intestine length	A_2-B_2** A_2-C_2* A_2-D_2*		
Large intestine fill	A_2-B_2** A_2-C_2* A_2-D_2***		

* Significant at $P < 0.05$

** Significant at $P < 0.01$

*** Significant at $P < 0.001$

APPENDIX 11

Chemical composition of faeces in experiment 4 (Dry matter basis)

Treat-ment	Pig No.	Period	DM	OM	CP	CF	EE	Ash	NFE
A_2	77	1	94.09	83.30	20.06	20.34	9.85	16.70	33.05
	112	2	95.56	77.24	19.29	17.76	10.97	22.76	29.22
	106	3	94.46	77.79	21.17	18.34	3.62	22.21	34.66
	75	4	92.69	76.57	20.18	17.66	3.25	23.43	35.48
B_2	112	1	91.03	81.95	25.19	31.82	6.49	18.05	18.45
	106	2	95.62	83.08	19.29	25.49	5.99	16.92	32.31
	75	3	93.36	81.93	21.10	29.49	3.82	18.07	27.52
	77	4	96.90	79.42	19.13	27.57	1.37	20.58	31.35
C_2	106	1	91.86	81.69	25.74	30.37	6.23	18.31	19.35
	75	2	95.47	83.13	16.50	26.36	5.23	16.87	35.04
	77	3	88.09	79.94	18.93	33.33	3.86	20.06	23.82
	112	4	95.04	81.95	23.30	31.03	2.09	18.05	25.53
D_2	75	1	92.04	77.61	30.61	22.03	7.97	22.39	17.00
	77	2	96.74	76.86	25.56	20.69	7.60	23.14	23.01
	112	3	95.61	80.68	26.41	23.18	7.89	19.32	23.20
	106	4	96.78	76.50	25.48	21.78	4.75	23.50	24.49

APPENDIX 12

Digestibility of diet A_2 in experiment 4

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	5107.8	4582.2	917.4	540.4	318.2	525.6	2806.2
Feed in faeces, g	1250.0	1041.3	250.8	254.3	123.1	208.8	413.1
Feed digested, g	3857.8	3540.9	666.6	286.1	195.1	316.8	2393.1
Dig. coeff. %	75.53	77.28	72.66	52.94	61.31	60.27	85.28
2.							
Feed intake, g	5107.8	4582.2	917.4	540.4	318.2	525.6	2806.2
Feed in faeces, g	1096.0	846.6	211.4	194.6	120.2	249.4	320.3
Feed digested, g	4011.8	3735.6	706.0	345.8	198.0	276.2	2485.9
Dig. coeff. %	78.54	81.52	76.96	63.99	62.20	52.55	88.59
3.							
Feed intake, g	5107.8	4582.2	917.4	540.4	318.2	525.6	2806.2
Feed in faeces, g	946.0	735.9	200.3	173.5	34.2	210.1	327.9
Feed digested, g	4161.8	3846.3	717.1	366.9	284.0	315.5	2478.3
Dig. coeff. %	81.48	83.94	78.17	67.89	89.25	60.03	94.35
4.							
Feed intake, g	5107.8	4582.2	917.4	540.4	318.2	525.6	2806.2
Feed in faeces, g	997.0	763.4	201.2	176.1	32.4	233.6	353.7
Feed digested, g	4110.8	3818.8	716.2	364.3	285.8	292.0	2452.5
Dig. coeff. %	80.48	83.34	78.07	67.41	89.82	55.55	93.91
Means	79.01	81.52	76.47	63.06	75.65	57.10	90.53

APPENDIX 13

Digestibility of diet B_2 in experiment 4.

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	5155.9	4848.1	805.4	403.2	127.4	307.8	3512.2
Feed in faeces, g	856.0	701.5	215.6	272.4	55.6	154.5	157.9
Feed digested, g	4299.9	4147.1	589.8	130.8	71.8	153.3	3354.3
Dig. coeff. %	83.40	85.54	73.23	32.44	56.36	49.81	95.50
2.							
Feed intake, g	5155.9	4848.1	805.4	403.2	127.4	307.8	3512.2
Feed in faeces, g	1080.0	897.3	208.3	275.3	64.7	182.7	348.9
Feed digested, g	4075.9	3950.8	597.1	127.9	62.7	125.1	3163.3
Dig. coeff. %	79.05	81.49	74.14	31.72	49.22	40.64	90.07
3.							
Feed intake, g	5155.9	4848.1	805.4	403.2	127.4	307.8	3512.2
Feed in faeces, g	1183.0	969.2	249.6	348.9	45.3	213.8	325.6
Feed digested, g	3972.9	3878.9	555.8	54.3	82.1	94.0	3186.6
Dig. coeff. %	77.05	80.00	69.01	13.47	64.44	30.54	90.73
4.							
Feed intake, g	5155.9	4848.1	805.4	403.2	127.4	307.8	3512.2
Feed in faeces, g	1131.0	898.2	216.4	311.8	14.8	232.8	354.6
Feed digested, g	4024.9	3949.9	589.0	91.4	112.6	75.0	3157.6
Dig. coeff. %	78.96	81.47	73.13	22.67	88.38	24.37	89.90
Means	79.39	82.13	72.38	25.08	64.60	36.34	91.55

APPENDIX 14

Digestibility of diet C_2 in experiment 4

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	5516.0	5118.8	896.4	524.0	316.1	397.2	3382.4
Feed in faeces, g	847.0	691.9	218.0	257.2	52.8	155.1	163.9
Feed digested, g	4669.0	4426.9	678.4	266.8	263.3	242.1	3218.5
Dig. coeff. %	84.64	86.48	75.68	50.92	83.30	60.95	95.15
2.							
Feed intake, g	5516.0	5118.8	896.4	524.0	316.1	397.2	3382.4
Feed in faeces, g	837.0	695.8	138.1	220.6	43.8	141.2	293.3
Feed digested, g	4679.0	4423.0	758.3	303.4	272.3	256.0	3089.1
Dig. coeff. %	84.83	86.41	84.59	57.90	86.14	64.45	91.33
3.							
Feed intake, g	5516.0	5118.8	896.4	524.0	316.1	397.2	3382.4
Feed in faeces, g	901.0	720.3	170.6	300.3	34.8	180.7	214.6
Feed digested, g	4615.0	4398.5	725.8	223.7	281.3	216.5	3167.8
Dig. coeff. %	83.67	85.93	80.97	42.69	89.00	54.51	93.66
4.							
Feed intake, g	5516.0	5118.8	896.4	524.0	316.1	397.2	3382.4
Feed in faeces, g	710.0	581.8	165.4	220.3	14.8	128.2	181.3
Feed digested, g	4806.0	4537.0	731.0	303.7	301.9	269.0	3201.1
Dig. coeff. %	87.13	88.63	81.55	57.96	95.51	67.72	94.64
Means	85.07	86.86	80.70	52.37	88.49	61.91	93.70

APPENDIX 15

Digestibility of diet D_2 in experiment 4

Periods	DM	OM	CP	CF	EE	Ash	NFE
1.							
Feed intake, g	5265.7	4922.9	805.1	252.2	388.6	342.8	3476.9
Feed in faeces, g	661.0	513.0	202.3	145.6	52.7	148.0	112.4
Feed digested, g	4604.7	4409.9	602.8	106.6	335.9	194.8	3364.5
Dig. coeff. %	87.45	89.58	74.87	42.27	86.44	56.83	96.77
2.							
Feed intake, g	5265.7	4922.9	805.1	252.2	388.6	342.8	3476.9
Feed in faeces, g	761.0	584.9	194.5	157.5	57.8	176.1	175.1
Feed digested, g	4504.7	4338.0	610.6	94.7	330.8	166.7	3301.8
Dig. coeff. %	85.55	88.12	75.84	37.55	85.13	48.63	94.96
3.							
Feed intake, g	5265.7	4922.9	805.1	252.2	388.6	342.8	3476.9
Feed in faeces, g	693.0	559.1	183.0	160.6	54.7	133.9	160.8
Feed digested, g	4572.7	4363.8	622.1	91.6	333.9	208.9	3316.1
Dig. coeff. %	86.84	88.64	77.27	36.32	85.92	60.94	95.38
4.							
Feed intake, g	5265.7	4922.9	805.1	252.2	388.6	342.8	3476.9
Feed in faeces, g	690.0	527.9	175.8	150.3	32.8	162.2	169.0
Feed digested, g	4575.7	4395.0	629.3	101.9	355.8	180.6	3307.9
Dig. coeff. %	86.90	89.28	78.16	40.40	91.56	52.68	95.14
Means	86.69	88.91	76.54	39.14	87.26	54.77	95.56

APPENDIX 16

Nitrogen output in faeces in experiment 4

Treat-ment	Pig No.	Period	DM %	% CP in faeces	% CP in faeces DM	g CP in faeces	g N in faeces	g N/day
A_2	77	1	32.7	6.56	20.06	250.76	40.12	5.73
	112	2	26.6	5.13	19.29	211.37	33.82	4.83
	106	3	26.6	5.63	21.17	200.22	32.04	4.58
	75	4	25.9	5.23	20.18	201.19	32.19	4.60
B_2	112	1	21.6	5.44	25.19	215.59	34.49	4.93
	106	2	25.3	4.88	19.29	208.32	33.33	4.76
	75	3	32.6	6.88	21.10	249.66	39.95	5.71
	77	4	22.9	4.38	19.13	216.32	34.61	4.94
C_2	106	1	25.1	6.46	25.74	217.99	34.88	4.98
	75	2	25.4	4.19	16.50	138.07	22.09	3.16
	77	3	28.1	5.32	18.93	170.58	27.29	3.90
	112	4	18.8	4.38	23.30	165.41	26.47	3.78
D_2	75	1	19.8	6.06	30.61	202.31	32.37	4.62
	77	2	24.8	6.34	25.56	194.55	31.13	4.45
	112	3	25.1	6.63	26.41	183.05	29.29	4.18
	106	4	22.1	5.63	25.48	175.78	28.12	4.02

APPENDIX 17

Nitrogen balance in experiment 4

Diet	Pig No.	DM feed/ day	g CP/ day	g N/ day	Faecal N/day, g	Dig. N/ day	Urin-ary N/ day	N-balance
A_2	77	729.7	131.1	21.0	5.7	17.3	10.1	+ 5.2
	112	729.7	131.1	21.0	4.8	16.2	9.9	+ 6.3
	106	729.7	131.1	21.0	4.6	16.4	7.6	+ 8.8
	75	729.7	131.1	21.0	4.6	16.4	6.2	+ 10.2
B_2	112	736.6	115.1	18.4	4.9	13.5	6.9	+ 6.6
	106	736.6	115.1	18.4	4.8	13.6	12.6	+ 1.0
	75	736.6	115.1	18.4	5.7	12.7	9.4	+ 3.3
	77	736.6	115.1	18.4	4.9	13.5	7.8	+ 5.7
C_2	106	788.0	128.1	20.5	5.0	15.5	11.1	+ 4.4
	75	788.0	128.1	20.5	3.2	17.3	8.9	+ 8.4
	77	788.0	128.1	20.5	3.9	16.6	6.4	+ 10.1
	112	788.0	128.1	20.5	3.8	16.7	9.2	+ 7.5
D_2	75	752.2	115.0	18.4	4.6	13.8	5.5	+ 8.3
	77	752.2	115.0	18.4	4.5	13.9	6.6	+ 7.3
	112	752.2	115.0	18.4	4.2	14.2	6.0	+ 8.2
	106	752.2	115.0	18.4	4.0	14.4	10.9	+ 3.5

APPENDIX 18

Nitrogen retention in experiment 4

Diet	Pig No.	Nitrogen retention % of intake	Nitrogen retention % of digested	Average daily gain, g
A_2	77	24.8	30.1	214
	112	30.0	38.9	214
	106	41.9	53.7	285
	75	48.9	62.2	428
Means		36.3	46.2	285
B_2	112	35.9	48.9	285
	106	5.4	7.4	71
	75	17.9	26.0	142
	77	31.0	42.2	142
Means		22.6	31.1	160
C_2	106	21.5	28.4	285
	75	41.0	48.6	357
	77	49.3	60.8	500
	112	36.6	44.9	285
Means		37.1	45.7	357
D_2	75	45.1	60.1	214
	77	37.7	52.5	214
	112	44.6	57.7	214
	106	19.0	24.3	71
Means		37.1	48.7	178

APPENDIX 19

Differences between means in experiment 4

Item	Levels of significance		
Digestibility of:			
Dry matter	A_2-C_2**	B_2-C_2**	
	A_2-D_2***	B_2-D_2***	
Organic matter	A_2-C_2**	B_2-C_2**	
	A_2-D_2***	B_2-D_2***	
Crude protein		B_2-C_2*	
Crude fibre	A_2-B_2***	B_2-C_2***	C_2-D_2*
	A_2-C_2*	B_2-D_2*	
	A_2-D_2***		
Ether extractives		B_2-C_2*	
		B_2-D_2*	
Ash	A_2-B_2**	B_2-C_2***	
		B_2-D_2**	
NFE	A_2-D_2*		
Average daily gain		B_2-C_2*	C_2-D_2 *
Metabolizable energy	A_2-C_2*	B_2-C_2**	
	A_2-D_2**	B_2-D_2***	

* Significant at $P < 0.05$

** Significant at $P < 0.01$

*** Significant at $P < 0.001$

APPENDIX 20

Differences between means in experiment 6

Item	Level of significance	
Average daily gain	A_4-B_4***	Barrows-Gilts***
	A_4-C_4***	_Ad lib_-Restricted***
	A_4-D_4***	Interaction**
Killing-out percentage	A_4-B_4**	Interaction**
	A_4-C_4*	
Empty body weight-E	A_4-B_4**	_Ad lib_-Restricted*
		Interaction*
Carcass length	A_4-C_4*	
	A_4-D_4*	
Backfat thickness	A_4-B_4***	Interaction**
	A_4-C_4***	
	A_4-D_4**	
Gastrointestinal tract, full	A_4-B_4**	B_4-C_4*

* Significant at $P < 0.05$

** Significant at $P < 0.01$

*** Significant at $P < 0.001$