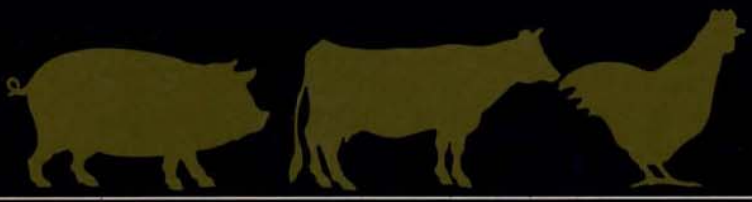
IDRC — 095e



CASSAVA AS ANIMAL FEED

Proceedings of a workshop held at the University of Guelph 18-20 April 1977

Sponsored by the International Development Research Centre and the University of Guelph

Editors:
Barry Nestel and Michael Graham

IDRC-095e

CASSAVA AS ANIMAL FEED

Proceedings of a workshop held at the University of Guelph, 18–20 April 1977

Editors: Barry Nestel and Michael Graham

Cosponsored by the

International Development Research Centre
and the
University of Guelph

Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen Street, Ottawa

Nestel, B.
Graham, M.
IDRC
University of Guelph IDRC-095e

Cassava as animal feed: proceedings of a workshop held at the University of Guelph, 18–20 April 1977. Ottawa, IDRC, 1977. 147p. tables.

/IDRC pub CRDI/. Compilation of workshop papers on the use of /cassava/-based /feed/s — discusses methionine /amino acid/ supplementation of cassava diets; metabolic pathways and their significance in /animal nutrition/; single-cell /protein/ production (use of /bacteria/ to convert cassava into microbial protein); /animal feeding/ systems for /swine/, /poultry/ and /cattle/; /feed production/ techniques such as pelleting. /List of participants/, /statistical data/.

UDC: 636.085 ISBN: 0-88936-142-8

Microfiche Edition $1

Contents

Foreword

The use of cassava as an animal feed, particularly in the European Common Market, has increased phenomenally during the last decade and during the present year the equivalent of more than 4 million tonnes of dried cassava is expected to be used in compound animal feeds in Europe. The use of both cassava root and foliage as animal feeds in other parts of the world, particularly in the producing countries themselves, is also increasing at a rapid rate. This book presents a *state of the art* review with respect to the use of cassava as an animal feed. It deals with the use of both the root and the aerial parts of the plant and also contains papers that discuss the production of single-cell protein from a cassava substrate.

This is the thirteenth publication in the IDRC Cassava Series and the tenth that covers the findings of a small workshop. Three previous workshop themes have related to cassava in nutrition. The first covered cassava toxicity associated with the presence of the cyanide radical in the plant, the second dealt with the market prospects for cassava as an animal feed, and the third embraced problems in the processing and storage of cassava. A number of research projects were identified at these workshops; several of them were subsequently funded by IDRC and some of the results from this research are described in this book.

This monograph covers the proceedings of a 3-day meeting that took place in the Animal Science Department, University of Guelph, Canada from 18 to 20 April 1977. The meeting consisted of six separate sessions.

The first session followed welcoming addresses from *Dean W. Tossell* of the University of Guelph and *B. L. Nestel* on behalf of IDRC. Three papers were presented relating to biochemical considerations in using rations with high levels of cassava. The opening paper by *A. A. Adegbola* of the Animal Science Department of the University of Ife in Nigeria discussed the role of methionine as an additive to cassava rations in relation to both its characteristics as an essential amino acid and its role as a sulfur donor in the detoxification of HCN. This was followed by *R. Hutagalung* of the Animal Science Department of the Agricultural University of Malaysia who painted a broad picture of the possible need for additives other than methionine in high cassava diets. Finally *D. C. Hill* from the Nutrition Department of the University of Guelph reported on work that had been conducted in his Department in recent years in relation to the detoxification of dietary cyanide and linamarin. The joint discussion on these three papers was opened by *C. Devendra* of the Malaysian Agricultural Research & Development Institute in Serdang (MARDI) and the session rapporteur was *Z. Müller* of Asia Research Ltd. in Singapore.

The second half-day session was devoted to the use of cassava in poultry rations. The first of the two papers in this session covered cassava rations for broilers and was given by *J. J. Montilla* from the Animal Science Department of the Central University of Venezuela in Maracay. He was followed by *T. A. Omole* from the Animal Science Department of the University of Ife who dealt with the subject in relation to layer rations. The discussion for this session was opened by *Jowayan Khajarern* from the Animal Science Department of the University of Khon Kaen in Thailand and the session rapporteur was *D. C. Hill.*

The second day of the workshop commenced with a session devoted to cassava in swine diets. The first paper covered the subject from a broad base and was given by *Sarote Khajarern* of the Animal Science Department at Khon Kaen

University. *G. Gómez* from CIAT in Colombia then dealt specifically with life-cycle swine feeding systems based on cassava. The joint discussion opener was *L. S. Castillo,* Director of the Dairy Training and Research Institute and a member of the Animal Science Department of the University of the Philippines at Los Baños, and the session rapporteur was *J. C. Alexander* from Guelph.

The fourth session of the meeting reviewed work that had been carried out at Guelph during the previous five years by an interdepartmental team working on single-cell protein production using cassava as a substrate. The initial paper was from the team leader *K. F. Gregory* of the Department of Microbiology who discussed the microbiological implications of the work. He was followed by *A. G. Meiering* of the Department of Engineering who described the engineering aspects of the fermentor built for this project. Subsequently *J. C. Alexander* described some of the animal nutrition work with laboratory animals fed the fermented product and finally *G. Gómez* from CIAT described some preliminary work that he and *J. Santos* had carried out in Colombia using a pilot plant that had been built and developed at Guelph and then shipped to Colombia for the type of feed trials that could only be carried out in a cassava producing area. *J. Valle-Riestra* from IDRC's Regional Office in Bogota, Colombia, opened the discussion on this session and *T. A. Omole* acted as rapporteur.

The third day of the meeting commenced with a session focusing on cassava leaf and processing technology. *A. Montaldo* of the Faculty of Agronomy of the Central University of Maracay, Venezuela, presented a comprehensive paper on the agronomic aspects of producing cassava foliage for animal feed. He was followed by *C. Devendra* from MARDI who brought together a wide range of very scattered knowledge on the use of both the leaves and roots of cassava in ruminant rations. The final paper in this session was presented by *Z. Müller* from Singapore who discussed some recent advances in cassava processing technology in relation to feed value and utilization. *P. Moore* of CIAT opened the discussion at this session by presenting recent unpublished data on the production and use of cassava foliage at CIAT and the discussion was reported on by *B. L. Nestel,* an IDRC Consultant from London, England.

The sixth and final session of the meeting was taken over by short reports by the five previous session rapporteurs whose statements along with those of the discussion openers have been synthesized by the editors, in a section entitled Discussion Conclusions. In addition, the references from the individual contributions have been combined in the final part of the book to form a comprehensive literature review.

IDRC is particularly grateful to the University of Guelph for providing the facilities for the meeting and also for organizing visits to the Animal Science and Nutrition Departments and to the University farm. Particular thanks are due to *K. F. Gregory* who handled the local logistics and to *P. Eastman* of IDRC's Head Office in Ottawa who organized the travel and financial arrangements.

Barry L. Nestel
Consultant
Agriculture, Food and Nutrition Science Program

Participants

Adegbola, A. A. Department of Animal Science, University of Ife, Ile-Ife, Nigeria

Alexander, J. C. Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Andrade, F. Ralston Purina International, 2801 Ponce de Leon Blvd., Suite 570, Coral Gables, Florida 33143 USA

Auston, F. J. C. A. Pemberton & Co. Limited, 124 The East Mall, Toronto, Canada M8Z 5M1

Bayley, H. Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Castillo, L. S. Dairy Training and Research Institute, University of the Philippines at Los Baños, College, Laguna, Philippines

Devendra, C. Malaysian Agricultural Research and Development Institute, Serdang, Selangor, Malaysia

Eastman, P. International Development Research Centre (IDRC), Box 8500, Ottawa, Canada K1G 3H9

Gómez, G. Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia

Graham, M. International Development Research Centre (IDRC), Box 8500, Ottawa, Canada K1G 3H9

Gregory, K. F. Department of Microbiology, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Hill, D. C. Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Hutagalung, R. I. Department of Animal Science, University of Agriculture Malaysia, Serdang, Selangor, Malaysia

Khajarern, J. M. Department of Animal Science, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand

Khajarern, S. Department of Animal Science, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand

Kuo, E. C. Y. Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Lumsden, J. H. Department of Pathology, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Meiering, A. G. School of Engineering, University of Guelph, Guelph, Canada N1G 2W1

Montaldo, A. Facultad de Agronomía, Universidad Central de Venezuela, Maracay, Venezuela

Montilla, J. J. Departamento de Producción Animal, Facultad de Ciencias Veterinarias, Universidad Central de Venezuela, Maracay, Venezuela

Moore, P. Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia

Müller, Z. O. Asia Research Pte. Limited, P.O. Box 91, Alexandra P.O., Singapore 3.

Nestel, B. L. 38 Hatchlands Road, Redhill, Surrey, England (former Associate Director, Agriculture, Food and Nutrition Sciences Division, IDRC)

Obuekwe, C. O. Department of Microbiology, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1

Oke, O. L. Chemistry Department, University of Ife, Ile-Ife, Nigeria
Omole, T. A. Department of Animal Science, University of Ife, Ile-Ife, Nigeria
Phillips, T. P. School of Agricultural Economics, University of Guelph, Guelph, Canada N1G 2W1
Spriet, F. Division Matériels pour les Matières Plastiques, Creusot-Loire, Usine de l'Ondaine, 42701 Firminy, France
Srivastava, V. K. Department of Microbiology, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1
Tossell, W. Dean of Graduate Studies, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1
Valle-Riestra, J. Centro Internacional de Investigaciones para el Desarrollo (CIID), Apartado Aéreo 53016, Bogotá, D.E., Colombia

Methionine as an Additive to Cassava-Based Diets

A. A. Adegbola[1]

Methionine is required by animals for the synthesis of proteins, as a major source of methyl groups, and in cassava-based rations, it serves as a source of sulfate ions for the purpose of detoxication. It shares this role with other sulfur-donors such as cystine, thiosulfate, and elemental sulfur.

The amino acid patterns of cassava leaf meal and cassava root meal show a deficiency of methionine. Added methionine may be required to improve the quality and utilization of dietary protein. In a properly balanced diet, additional methionine may be required primarily for the detoxication of prussic acid released in the hydrolysis of linamarin and lotaustralin.

Levels of 0.2–0.3% methionine, for poultry, and 0.2% methionine for pigs have been used in rations for these species and positive responses in terms of growth performance have been obtained in most cases. Attention is drawn to the need to relate responses to added methionine in rations to the levels of protein in the diet as well as to the physical nature and palatability of the feed. There is a need to relate the results of added methionine to the levels of cysteine plus methionine in order to further explain the contradictory observations on urinary thiocynanate, particularly in swine.

Methionine is an essential amino acid, and like other amino acids its primary role in nutrition is for the synthesis of proteins. Animals are dependent on their food for their supply of methionine. Body requirements for methionine, like other amino acids, can be influenced by other dietary factors such as level of protein, energy, vitamin B_{12}, folate, and the levels of certain other amino acids. In this regard, the level of cystine and/or cysteine in animal diets is of importance and the usual consideration appears to be for a combined requirement of the sulfur-containing amino acids, a proportion of which must be methionine in animal diets.

A consideration of the metabolism of methionine indicates its other role in nutrition as that of a major source of methyl groups in the body. In its active form of S-adenosylmethionine, methyl groups can be transferred for example to guanidoacetic acid to form creatine or to nicotinamide to form N-methylnicotinamide or to phosphadidyl-ethanolamine to form lecithine 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. For the complete breakdown of homocysteine, serine and/or glycine are required to form cystathionine, which then breaks down irreversibly to cysteine and cystine, the other sulfur containing amino acids. The final oxidation of these latter acids results in the production of sulfate ion, pyruvate, and ammonia.

If the main rational for supplementing cassava diets with methionine is as a source of sulfate ions for the purpose of detoxication of the cyanide present in food, then from the purely biochemical point of view, this role of detoxication cannot be a property of methionine alone but of all sulfur containing amino acids. Olson et al. (1969)[2] obtained results that demonstrated that supplementation of cassava chick diets with 0.2% methionine gave equal performance to 0.4 or 0.8% cystine addition to the diet. Methionine may, however, be preferred as an additive because it is an essential amino acid and when metabolized it yields cystine and cysteine and can thus be a source of these sulfur-containing amino acids where these are deficient. Generally, livestock rations based on cassava roots and leaves have used soybean meal and groundnut cake as sources of protein. These two protein concentrates are

[1]Department of Animal Science, University of Ife, Ile-Ife, Nigeria.

[2]All references in this monograph have been combined to form a comprehensive literature review (see p. 131).

deficient in methionine. Added methionine therefore helps to improve the protein quality of the rations.

Protein Quality of Cassava

To understand the effect of adding amino acids to cassava-based rations, it is useful to examine the quality of the protein in cassava roots and leaves. Rao et al. (1951) analyzed purified tapioca protein with an ash content of 1.03% for nitrogen (10.5%) and for amino acids (calculated on g/16 g N basis). The approximate composition was arginine 8.2, histidine 3.5, tyrosine 1.3, tryptophan 1.7, cystine 2.6; the sample contained no methionine. Similarly, FAO in 1970 noted that cassava meal contained only 22 mg/100 g of methionine (compared with 182 mg/100 g for maize) and that cassava was generally deficient in the sulfur amino acids.

The effect of heat treatment on the protein quality of cassava leaves was investigated by Pechnik and Guimaraes (1962). Meals prepared from leaves dried at room temperature promoted growth of Wistar rats at a slow, subnormal rate, while meal obtained from leaves dried at 70–80 °C for 24 h produced no growth response unless the diet was supplemented with methionine and lysine. When the meal was prepared with cassava leaves dried at 70–80 °C for 24 h, boiled, and redried, it did not stimulate growth even when supplemented with lysine, methionine, and threonine. Further, Pecknik and Guimaraes (1963) prepared meals from sweet cassava leaves dried at room temperature (25 °C) and in a refrigerator (5 °C). They concluded that the diet containing material dried at 5 °C proved to be superior, except when supplemented with lysine and histidine. The best growth response was produced with diets supplemented with methionine alone and the minimal amount required to produce optimal feed efficiency was 0.3%.

Eggum (1970) fed rats diets in which all the N was derived from the protein of leaves of three cassava cultivars and reported an average true digestibility of 72.97%, a low biological value of 53.37%, a much lower net protein utilization of 38.93%, and utilizable nitrogen of 2.17%.

Amino acid profiles of cassava leaves by Eggum (1970) and Rogers and Milner (1963) indicate a low content of methionine and cystine in the leaf protein (Table 1). Ross and Enrique (1969) also estimated the level of methionine in cassava leaf meal to range between 0.25 and 0.32% and that of cystine as 0.18–0.23% as fed. The content of other essential amino acids appears to be adequate, especially that of lysine for chick diets.

When 50% of the nitrogen was supplied by dried cod fish and 50% by cassava leaf, the

Table 1. Amino acid profiles (%) for cassava leaf protein dry matter (Rogers and Milner 1963; Eggum 1970).

	Jamaican samples (average)	Brazilian samples (average)	Nigerian samples (average)	Average for all samples (as fed) 20% of diet	NRC requirements for chicks (0–6 wks)
Arginine	5.54	6.49	5.89	1.18	1.2
Glycine and/or	5.66	5.64	5.55	1.10	1.0
Serine	5.42	4.88	5.31	0.27	—
Histidine	2.34	2.71	2.60	0.50	0.4
Isoleucine	5.26	5.13	5.04	1.01	0.75
Leucine	9.33	9.38	9.29	1.83	1.4
Lysine	7.56	6.71	6.64	1.37	1.1
Methionine	1.73	1.81	2.13	0.37	0.75 (or 0.40)
Cystine	1.44	1.10	1.65	0.27	0.35
Phenylalanine	6.11	5.86	5.64	1.15	1.3 (or 0.7)
Tyrosine	4.39	4.17	4.46	0.85	0.6
Threonine	5.17	5.01	5.15	1.00	0.7
Tryptophan	1.54	2.91	2.36	0.40	0.2
Valine	6.02	5.91	6.36	1.19	0.85

biological value of the protein in the diet increased to 72.8% and to 80.4% when the cassava leaf diet was supplemented with methionine. Similarly, net protein utilization was 36.4, 58.7, and 56.5% for diets in which the protein N source was cassava leaf meal, cassava–cod, and methionine supplemented cassava, respectively (Eggum 1970). The effects of methionine on protein utilization by rats have since been confirmed (Maner and Gomez 1973, and Job 1975).

Biochemical Considerations

Protein from cassava leaves and roots contains inadequate quantities of the sulfur amino acids. When fed with groundnut cake (0.4% methionine) or soybean meal (0.7% methionine), both of which are deficient in methionine, there is a methionine deficiency per se that is bound to affect the overall utilization of the dietary protein either by poultry or pigs. One possibility therefore is for the dietary protein quality to be improved by the addition of crystalline DL-methionine (Rogers and Milner 1963; Eggum 1970; Maner and Gomez 1973; Job 1975).

A second possibility is that the added methionine is primarily required for the detoxication of prussic acid released on the hydrolysis of the two major cyanogenic glucosides of cassava, linamarin and lotaustralin. Linamarin yields free HCN acetone and D-glucose on enzymatic or acid hydrolysis, whereas lotaustraline yields free HCN, 2-butanone, and D-glucose in the same process (Nartey 1973). The content of HCN varies markedly in cassava roots depending on soil humidity, plant part, tuber, rind, and flesh. Sinha et al. (1968) reported HCN contents of 275–490 mg/g in cassava root meal (rind plus flesh) for better varieties of *Manihot utilissima* and 35–130 mg/g in root meal of the sweet varieties *M. aipi* in India.

Lang (1894, 1895) suggested that the formation of thiocyanate was the principal route for detoxication of cyanide in animals and that the liver was the chief site of detoxication. Later in 1933, Lang postulated the occurrence of the enzyme rhodanese in various body tissues and stated that this enzyme was responsible for the conversion of the cyanide ion to thiocyanate under aerobic conditions in the presence of thiosulfate colloidal sulfur:

$$HCN + Na_2S_2O_3 \rightarrow HSCN + Na_2SO_3$$

Himmich and Saunders (1948) working on the distribution of the enzyme rhodanese in tissue homogenates concluded that the thiosulfate ion was the only sulfur containing compound capable of efficiently providing sulfur in his in vitro system. Later, Wood and Cooley (1956) noted that the reaction of cyanide with cystine yields cysteine and β-thiocyanoalanine, which tautomerizes to 2-aminothiazolidine-4-carboxylic acid or the equivalent 2-imino-4-thiazolidine carboxylic acid. Further, when 2-imino-4-thiazolidine was administered to rats, it was not converted to cysteine or to thiocyanate. When cyanide entered the body 2-imino-4-thiazolidine carboxylic acid was excreted in the urine. It was therefore concluded that this reaction constitutes a new, independent pathway for detoxication of cyanide in the body.

A comprehensive review of the mode of cyanide detoxication was presented by Oke (1973) who also pointed out that vitamin B_{12} occurring as hydroxocobalamin can react with cyanide to give cyanocobalamin constituting another pathway for cyanide detoxication. Further, he noted that 3-mercaptopyruvic acid arising from cysteine by transamination or deamination can provide sulfur as rapidly as thiosulfate for cyanide detoxication and also that powdered sheep thyroid gland shows some detoxicating effect on cyanide when administered to mice. The major reactions so far known to be involved in cyanide detoxication are shown in Fig. 1. The diagram suggests that thiosulfate and not methionine per se is the required substance for the formation of thiocyanate by rhodanese and that to make methionine-sulfur available for detoxication purposes, methionine has to be metabolized. Indeed, there is ample evidence in the literature to support the view that other sulfur-donors can be responsible for the detoxication of cyanide originating from diets in ruminant animals. For example in 1949, Blakley and Coop concluded that HCN in sheep is rapidly detoxified in the rumen and liver by reactions with sulfide or cystine and calculated that approximately 1.2 g of sulfur are required to detoxify each gram of HCN ingested.

In 1975, Wheeler et al. concluded that a significant part of the sulfur ingested by animals grazing *Sorghum* spp. may be used in detoxication of the HCN produced from dhurrin during digestion in the rumen. They observed that sheep grazing a sorghum × sudan grass hybrid, and allowed access to salt licks contain-

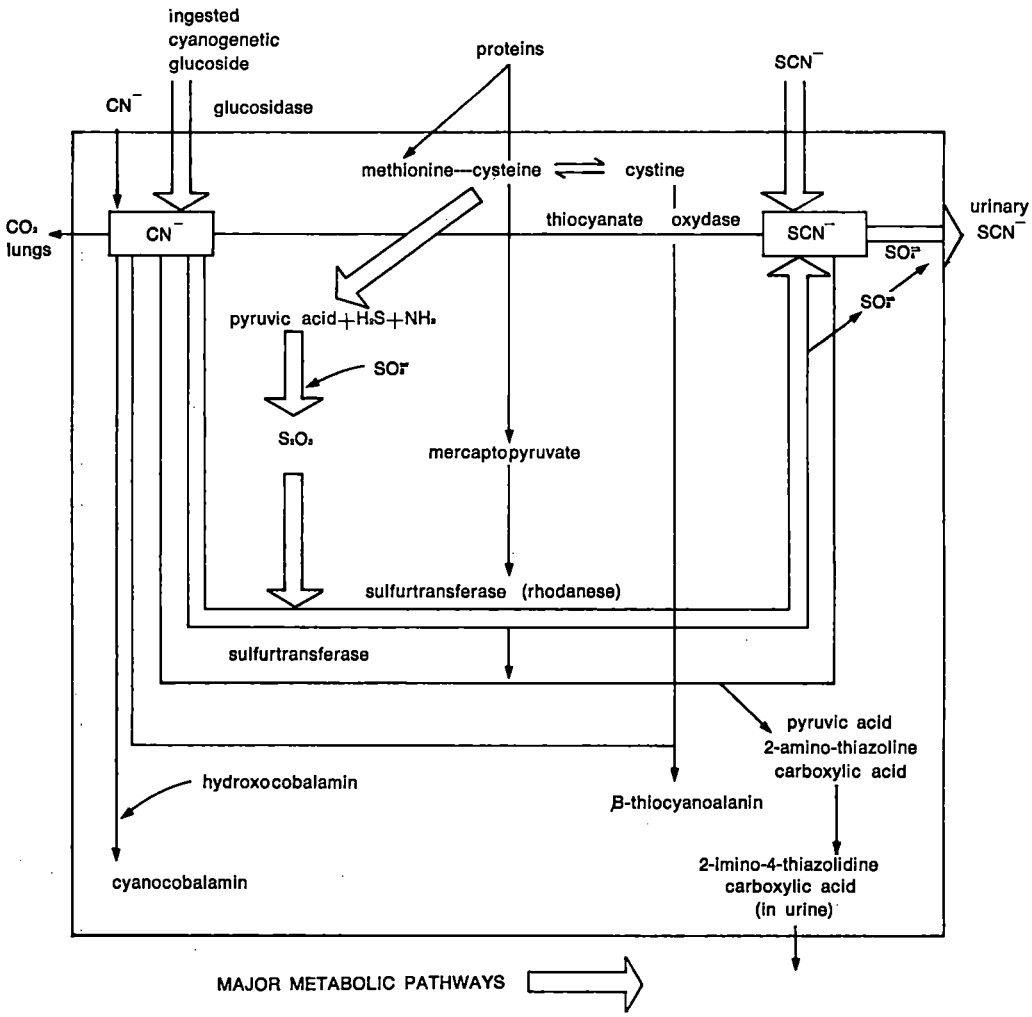


Fig. 1. Principal metabolic pathways of the cyanogenetic glucosides, cyanide and thiocyanate (after Job 1975).

ing 18% S, showed 32% higher ($p < 0.05$) liveweight gains than the control sheep on 0.1% sulfur licks. Sheep grazing forage fertilized with 84 kg N/ha and given access to licks containing 8.5% S gained 32% more liveweight than controls with 0.1% S licks, whereas sheep on 168 kg N/ha forage on 8.5% S licks gained 88% more than the control sheep. The possibility that rumen microorganisms can synthesize methionine from elemental sulfur sources cannot be ruled out. The synthesis of methionine from cysteine and cystine by microorganisms in the presence of vitamin B_{12} has already been demonstrated by Horowitz (1947).

The effect of other sulfur donors in detoxication is not restricted to ruminants alone. Similar effects have been observed in poultry feeding. Thus Ross and Enrique (1969) demonstrated that when additional sulfur as 0.15% $Na_2S_2O_3 \cdot 5H_2O$ (sodium thiosulfate) was supplied to chicks on a 20% cassava-leaf diet, the 8-day body weight (74.3 g), as well as the feed/gain ratio (2.18) compared favourably with the body weight (72.8 g) and feed/gain ratio (1.75) of chicks fed 0.2% methionine-supplemented 20% cassava-leaf meal diets. Van Weerden et al. (1976) working with 0–5-week-old broiler chicks in battery cages examined the possibility of re-

ducing the requirements for sulfur amino acids in the ration by addition of inorganic sulfate. To a basal broiler ration of corn and soybean meal containing 0.73 methionine plus cystine, 0.1% Na_2SO_4 supplying 0.068% inorganic sulfate was added. The diets were supplemented with 0.78, 0.82, 0.92, or 1.02% methionine, plus cystine. The addition of the sulfate produced an increase in weight gain at 5 weeks of 0.9% and a reduction in feed conversion of 1.2%, both effects were significant at $p < 0.5$ and not related to the contents of methionine and cystine.

Similar effects of other sulfur donors to the detoxication process will be discussed later in relation to swine production. For now, attention should be drawn to the report by Maner and Gomez (1973) that methionine supplementation significantly improved body growth and feed conversion of rats and pigs, and led to an increase in urinary excretion of thiocyanate. Job (1975), on the other hand, reported that the addition of methionine to a cassava meal diet produced a reduction in urinary thiocyanate excretion. This apparent contrast suggests the need for further study of the significance of different biochemical pathways of detoxication as they relate to the proportion of cystine to methionine in the ration of swine diets.

Addition of Methionine to Cassava-Based Rations

Root-Meal Based Diets for Poultry

The earliest report on supplementing a cassava-based diet with methionine is that of Enriquez and Ross (1967), who fed up to 50% cassava to poultry with or without 4% molasses and 3.7% soybean oil. They observed consistent but not always significant improvement in body weight when the cassava ration was supplemented with 0.15–0.20% DL-methionine (Table 2). Similar effects were obtained for other dietary supplements and methionine on feed conversion. Neither soybean oil alone nor molasses alone had any beneficial effect on feed utilization without methionine; however, they improved performance when added to methionine supplemented rations. They concluded that when the ration was well balanced with respect to protein and methionine, up to 50% cassava root meal satisfactorily replaced corn in the diet. Molasses probably improved the palatability of the cassava diet, whereas soybean oil reduced its dustiness and improved its content of essential fatty acids.

Table 2. Body weights (g) and feed conversion of 3-week-old White Leghorn cockerel chicks fed 50% cassava root meal supplemented with soybean oil or molasses singly or in combination with methionine (Enriquez and Ross 1967).[1]

	Body weight	Feed/gain
0% cassava	214^{a}	2.14^{ab}
50% cassava	191^{b}	2.28^{bcd}
Supplement to 50% cassava diet:		
4% molasses	187^{bc}	2.39^{cd}
3.7% soybean oil	178^{c}	2.43^{cd}
0.15% methionine	213^{a}	2.10^{ab}
0.20% methionine	213^{a}	2.09^{ab}
0.15% methionine + 4% molasses	211^{a}	2.19^{abc}
0.20% methionine + 4% molasses	219^{a}	2.06^{ab}
0.15% methionine + 3.7% soybean oil	214^{a}	2.05^{ab}
0.20% methionine + 3.7% soybean oil	219^{a}	1.96^{a}

[1]Means in any one column with the same superscript do not differ significantly ($p < 0.01$).

These results have essentially been confirmed by Gadelha et al. (1969) using 336 one-day-old Shaver starboro chicks of both sexes on 0, 15, 30, and 45% levels of cassava diets supplemented with 0.2% DL-methionine. They observed that with increasing levels of cassava meal, chicks gained weight more slowly and required more feed/kg of gain. The chicks also consumed less food with increasing levels of cassava meal although the differences were not significant.

Scientists at the University of Wisconsin (Anonymous 1970) reported that 0.20% supplemental methionine in chick diets comprised of 45% cassava meal gave optimum result, although substituting cassava meal for maize increased the chicks' requirement for methionine.

Leaf-Meal Based Diets for Poultry

Poor utilization of unsupplemented cassava-leaf meal rations by chicks may be attributed to an increase in fibre and a decrease in energy content, as well as an increased requirement for sulfur amino acids to overcome an induced methionine imbalance (Ross and Enriquez 1969). These workers observed that the addition of 0.2% methionine to the positive con-

Table 3. Body weight (g) and feed conversion of 3-week-old W.L.H. cockerel chicks fed 20% cassava leaf meal and graded levels of methionine (Ross and Enriquez 1969).[1]

	Body weight	Feed/gain
0% cassava leaf meal (CLM)	208[a]	2.10
0% CLM + 0.2% methionine	220[a]	1.99
20% CLM alone	144[c]	2.73
20% CLM + 0.2% methionine	185[c]	2.32
20% CLM + 0.3% methionine	211[ab]	2.18
20% CLM + 0.4% methionine	205[ab]	2.35
20% CLM + 0.5% methionine	202[ab]	2.18

[1]Means in any one column with the same superscript do not differ significantly ($p < 0.01$).

Table 4. Body weight gain (g) and feed conversion of 3-week-old W.L.H. cockerel chicks fed 15 and 20% cassava leaf meal supplemented with either molasses, soybean oil, and/or methionine (Ross and Enriquez 1969).[1]

	Body weight	Feed/gain
0% cassava leaf meal (no supplement)	219[a]	1.86
15% cassava leaf meal		
+ 0.15% methionine	175[b]	2.17
+ 5% molasses	154[c]	2.46
+ 0.15% methionine and 5 % molasses	177[b]	2.32
20% cassava leaf meal		
+ 0.15% methionine	177[b]	2.11
+ 0.20% methionine	191[ab]	2.06
+ 3.0% soybean oil	140[c]	2.45
+ 0.15% methionine and 3.0% soybean oil	192[ab]	2.06
+ 0.20% methionine and 3.0% soybean oiil	212[a]	2.14

[1]Means in any one column with the same superscript do not differ significantly ($p > 0.01$).

trol, i.e. 0% cassava-leaf meal diet, improved growth and feed conversion (Table 3) showing that there might have been a marginal methionine deficiency in the ration. Table 3 also shows that when increasing levels of methionine were added to 20% cassava-leaf meal rations, body weight and feed conversion were improved by each increment up to 0.3% methionine, although the feed conversion was not as low as that of the methionine supplemented control group. This suggests that the 20% cassava-leaf meal may have less available energy than the positive control group.

Table 5. Effect of methionine and fat supplementation on the utilization of cassava by growing pigs (Maner 1974).

	Daily gain (kg)	Feed/gain
Control corn/soybean meal	0.74	2.81
55% cassava meal (CM)	0.76	2.61
55% CM + 0.1% methionine	0.83	2.46
55% CM + 0.2% methionine	0.82	2.49
55% CM + 10% beef tallow + 0.1% methionine	0.80	2.35
55% CM + 10% beef tallow + 0.2% methionine	0.74	2.21
55% CM + 10% beef tallow	0.85	2.24

Ross and Enriquez (1969) also observed that the addition of both molasses and soybean oil to methionine supplemented 20% cassava-leaf meal diets had no effect on body weight gains and feed conversion of 3-week-old white leghorn cockerel chicks (Table 4).

Root-Based Diets for Swine

Hew and Hutagalung (1972) found decreasing feed intake in growing swine when their dietary level of cassava meal was increased. They added 0.2% methionine to the 50% cassava-based diet and this significantly improved performance. The addition of 0.4% methionine to the ration did not improve animal performance although when palm oil was added to the high methionine ration, liveweight gains and feed conversion were improved. They suggested a possible interaction between the fatty acids present in the palm oil and the methionine in the diet. This is not likely because cassava-based rations may be deficient in essential fatty acids as well as in amino acids, e.g. linoleic acid.

Similar results for added methionine have been reported by Maner and Gomez (1973) who observed an increase in urinary thiocyanate in pigs fed methionine supplemented cassava-based diets. Maner (1974) reported overcoming the slight depression in average daily gain by supplementing a fat-and-molasses supplemented 55% cassava meal diet for pigs with 0.1 and 0.2% methionine (Table 5). They suggested that the methionine was required to overcome sulfur-amino deficiency and to supply labile sulfur for detoxication of the HCN cassava. The fat (as tallow) was

Table 6. Effect of dietary supplemental sulfur source on the performance of growing pigs fed dried bitter cassava rations (Job 1975).[1]

		Control + supplement		
	Control	Methionine	$Na_2S_2O_3 \cdot 5H_2O$	Sulfur
Average daily gain (kg)	0.67	0.70	0.61	0.65
Feed/gain	2.43	2.29	2.32	2.29
Average daily protein intake (kg)	2.32	0.29	0.28	0.28
Protein efficiency ratio	2.09[b]	2.39[a]	2.22[ab]	2.32[a]
Average serum thiocyanate (mg/100 ml)	1.25	1.38	1.19	1.34
Average serum thiocyanate (mg/100 ml)[2]	2.63	3.60	2.82	3.07
Urinary thiocyanate (mg/kg feed)	19.31[b]	17.53[b]	23.76[a]	20.76[ab]
Urinary thiocyanate (mg/kg feed)[2]	56.51	50.73	66.19	61.20
Urinary nitrogen excretion (%)	30.46	28.45	30.23	33.85
Urinary nitrogen excretion (%)[2]	27.62[ab]	30.96[a]	22.46[c]	25.25[bc]
Urinary sulfur excretion (mg/kg feed)	4.18[c]	5.33[c]	17.19[a]	7.05[b]
Urinary sulfur excretion (mg/kg feed)[2]	3.76[b]	4.62[b]	17.66[a]	4.46[b]

[1]Values with the same superscript are not significantly different ($p = 0.05$).
[2]300 ppm CN^- added as KCN to the 90 ppm CN^- contained in the 70% bitter cassava meal (determined by hydrolysis with added linamarase).

added to reduce dustiness and the molasses to improve palatability.

A lack of significance of the effect of added methionine to swine diets has been observed by Job (1975). He fed growing pigs basal rations of 71% bitter cassava meal plus 24.5% soybean meal supplemented with 0.2% methionine, 0.785% sodium thiosulfate, or 0.2% elemental sulfur. He observed that none of the three supplemental treatments had any effect on the average daily gains, average daily dry matter intake, feed efficiency, or serum thiocyanate concentration of the growing pigs. Methionine or elemental sulfur supplementation significantly ($p < 0.05$) improved the efficiency of protein utilization of pigs on these treatments compared with the unsupplemented control. Only the sodium thiosulfate treatment significantly increased urinary thiocyanate and sulfur excretion. There was no significant improvement in the protein efficiency ratio compared with the control (Table 6). These results suggest that 71/25% cassava-soybean meal probably supplied enough sulfur-amino acids to meet the needs of growing pigs and that there was no need to add methionine or any other sulfur source to handle detoxication of cyanide at the level likely to be encountered in a dried cassava-based ration.

When 300 ppm CN^- was added to the ration as KCN, there were significant differences in urinary thiocyanate, and urinary nitrogen and sulfur excretion, although the level of serum thiocyanate did not appear to be affected (Table 6). The amount of cyanide ingested appears to be the principal factor controlling the need for an external sulfur source in pig diets. Growing pigs may be able to make use of other sources of added sulfur as well as methionine.

Leaf-Based Diets for Swine

Incorporating 10–20% cassava leaf-meal into the rations of growing-finishing pigs, Lee and Hutagalung (1972a,b) demonstrated that cassava-leaf meal diets reduced palatability, and depressed weight gains and feed conversion. The addition of either 0.2% methionine or 0.15% sodium thiosulfate to the 20% cassava-leaf meal diet tended to improve (nonsignificantly) the performance of growing pigs. The effect of adding palm oil and molasses to the methionine supplemented cassava rations appears to be marginal and not of any major significance. The levels of cyanide in the diets did not produce any toxic symptoms throughout the experiment and confirmed the view that there may not be any need for additional methionine in a ration that is judged adequate in terms of its sulfur-amino acid content for growing-finishing swine. There seems to be no effect from adding excess methionine to the ration, although it may lead to an additional requirement of other amino acids, for example, glycine and/or serine.

Cassava-Based Rations for Rabbits

Work at the University of Ife on feeding cassava diets to rabbits demonstrated that the rate of gain decreased with increasing levels of

Table 7. Effect of feeding methionine (0.2%) supplemented cassava rations on the performance of fryer rabbits.

	Control		15% cassava		30% cassava		45% cassava	
	+ meth	− meth	+ meth	− meth	+ meth	− meth	+ meth	− meth
Weight gain (g/day)	18.91	18.50	18.56	17.53	18.12	17.45	16.67	16.59
Feed intake (g/day)	59.40	55.41	63.92	59.19	61.64	59.67	58.00	63.14
Feed/gain	3.14	2.98	3.47	3.37	3.40	3.42	3.22	3.83
Urinary thiocyanate (mg/ml)	3.0	3.0	5.40	5.40	5.70	5.60	4.65	5.40

cassava in the ration, although this decrease was not significant until the ration contained 45% cassava root meal (Omole and Eshiett 1976). Preliminary results show that the addition of 0.2% methionine to the control and 45% cassava diets resulted in very slight improvement (0.22 and 0.48%, respectively) in live weight gain over the unsupplemented diets. When the 15 and 30% cassava diets were supplemented, however, there was a 5.9 and 3.5% gain over the unsupplemented rations (Table 7). Addition of methionine to the ration did not improve the efficiency of feed utilization significantly; neither did it affect the quantity of urinary thiocyanate excreted by the animals. In the absence of any stated methionine requirement for grower rabbits, it is difficult to reach any valid conclusions based on this single study. The results merely show some interesting results and have implications as to the need for additional methionine for rabbits fed cassava-based rations.

Conclusions

There is a suggestion from the literature that care must be taken in reaching any firm conclusion as to the need for added methionine per se in the diets of poultry and pigs fed cassava-based rations. Although there is a positive response to levels of 0.2–0.3% methionine (for poultry) and 0.22% (for pigs) in the ration in terms of growth performance, in almost all cases, the responses have not been related to the levels of methionine plus cystine present in the rations fed or to the level of cyanide present in the meals. The overall protein and digestible energy levels of the rations are also factors that should be taken into consideration in specifying the need for added methionine. In some instances, the physical nature and palatability of the feed will affect intake and hence adequacy of its methionine supply for growth purposes. In these cases, the addition of palm oil, tallow, and molasses help to improve overall feed intake.

The major reasons for methionine addition are to correct the low content of sulfur-amino acids in the ration and thus improve the quality of dietary protein, and to serve as a readily available source of sulfur for cyanide detoxication. The increase in urinary thiocyanate obtained from animals fed methionine by some workers (Maner and Gomez 1973; Maner 1974) has not been confirmed by others (Job 1975). However, Job (1975) obtained increased urinary thiocyanate with the addition of sodium thiosulfate to the diet of pigs, suggesting that thiosulfate might be a better source of sulfur for detoxication of cyanide in swine than methionine. The need for additional methionine for the purpose of detoxication can be met by the addition of other sulfur-donating compounds to the diet, although these cannot replace methionine in a ration normally deficient in this amino acid. For a ration balanced in proteins and amino acids there may not be a need for supplementation.

The cost of supplementation may also be high, particularly in the developing countries where crystalline DL-methionine is not always readily available and has to be imported. In such countries, it may be cheaper to use thiosulfate, elemental sulfur, or in some cases, feed a high protein level. Babatunde et al. (1976) supplemented low protein diets for broiler chicks with methionine and concluded that the growth stimulation obtained for the supplemented diets was not enough to surpass the response to the 24% unsupplemented protein control. They concluded that in the Nigerian situation, a high protein diet unsupplemented with methionine was more economical to feed to broilers than methionine supplemented low protein diets. Similarly, at a 24% protein level, Job (1975) found no need for supplementing

a 70% cassava-based ration with additional methionine, thiosulfate, or elemental sulfur. Therefore, for both poultry and swine, primary consideration should be given to the adequate balance of protein and energy levels, as well as to adequate supply of sulfur-amino acids, to palatability, and to improving intake, before considering the addition of DL-methionine or of any other sulfur-donating compounds when feeding cassava-based diets. Little work has been reported on supplementing cassava-based diets for ruminants with methionine, although there have been positive responses to increased supply of dietary sulfur by sheep grazing sorghum and sudan grass.

Additives Other than Methionine in Cassava Diets

R. I. Hutagalung[1,2]

The problems of nutritional insufficiencies and metabolic diseases associated with feeding cassava-based diets and the roles of feed additives intended to alleviate these are discussed. Improvements in the nutritive value of cassava-based diets with feed additives can be made through: (1) adjustments in the energy (nutrient) density by adding fats or oils, sugars, or molasses and balancing the source and level of protein, amino acids, minerals, vitamins, and pigments; or (2) enrichment by microbial fermentation. The primary consideration in the improvement of cassava products through either feed additive fortification or microbial enrichment should be the economic feasibility of substitution with conventional feedstuffs and their safety for animal feeds, and the suitability of the subsequent animal products for human consumption.

Cassava (*Manihot esculenta*) has been widely used as a feedstuff and provides a major source of energy for livestock in Asia, Africa, Europe, and South America (Nestel 1975). However, numerous research findings and field reports have indicated that its extensive use in poultry and swine feeds has encountered some nutritional problems and diseases, including: its low protein, mineral, and vitamin content (Table 1); variation in HCN content resulting in acute and chronic toxicity, i.e., ataxic neuropathy; suspected goitrogenic substances causing iodine deficiency (goitre); reduction in availability of certain mineral elements resulting in zinc parakeratosis in pigs; low palatability due to dry texture, high ash, and crude fibre content causing poor digestibility and diarrhea; enzyme-inhibiting factors causing poor absorption of vitamins and minerals; poor performance and lack of skin and egg yolk pigmentation; and contamination by pathogenic microorganisms causing aflatoxicosis (Hutagalung and Tan 1976). Nevertheless, these problems are not confined only to feeding of cassava but they have been encountered in feeding other feedstuffs, such as rice bran, soybean, and cottonseed meal.

Within the last decade, efforts have been made by various workers to overcome these problems and to improve the nutritive value of cassava by investigating the effects of supplementation of nutritive and nonnutritive feed additives to cassava-based diets. These additives include: source and level of energy and protein, synthetic amino acids, minerals, vitamins, antibiotics and antifungals, pigments, flavouring agents, hormones, and enzymes.

To cover such a wide range of subjects is a difficult one. Moreover, conflicting results from animals given diets containing high levels of cassava present problems of interpretation. It is hoped that from this workshop a uniform guideline for animal nutritionists to assess accurately the nutritional value of cassava products can be formulated. Likewise, standard specifications for the cassava products should be adopted to ensure valid comparisons can be made from different localities.

Nutritive Feed Additives in Cassava-Based Diets

Energy

Energy required by livestock for growth of body tissues, production of eggs, performance of vital physical activities, and maintenance of normal body temperature, is derived from carbohydrates, fats, and protein in the diet. The most efficient nutrition of livestock is obtained when the diet contains the exact proportion of energy to other nutrients required to produce the desired growth, meat, milk and egg production, or body finish. The energy level of the diet appears to be the most important factor determining feed intake. The nutritionist must consider energy in terms of the digestible starch, sugars, fats, and protein in the feedstuff and must consider how processing of the ingredients, balancing of the diet, and addition of special supplements such as antioxidants or enzymes may aid in providing the animals with the maximum amount of usable energy. Scott et al. (1969) stated that in diets containing adequate amounts of all required nutrients, the efficiency of feed utilization depends upon the metabolizable energy content of the diet.

[1]Department of Animal Science, University of Agriculture Malaysia, Serdang, Selangor, Malaysia.

[2]The author acknowledges the assistance of IDRC for the travel grant sponsorship to attend and present this paper.

Table 1. Proximate analysis and amino acid composition of cassava roots and leaves (Hutagalung et al. 1973).

	Leaves	Roots
Proximate analysis[1]		
Dry matter	90.00	89.00
Ash	5.50	1.60
Crude fibre	15.90	2.70
Ether extract	6.30	1.20
N-free extract	37.30	81.20
Protein (N × 6.25)	25.00	2.30
Gross energy (kcal/g)	5.30	4.20
Calcium	1.40	0.35
Phosphorus	0.25	0.40
Copper (mg/kg)	8	—
Iron (mg/kg)	450	8
Manganese (mg/kg)	46	18
Zinc (mg/kg)	28	—
Amino acids[2]		
Arginine	1.48	0.29
Histidine	0.66	0.07
Isoleucine	1.67	0.03
Leucine	2.72	0.31
Lysine	1.87	0.07
Methionine	0.36	0.03
Phenylalanine	0.92	0.03
Threonine	1.35	0.03
Tryptophan	0.24	—
Valine	0.99	0.04
Alanine	1.70	0.15
Aspartic acid	2.44	0.13
Cystine	0.21	0.01
Glutamic acid	1.99	0.15
Glycine	1.73	0.01
Proline	0.88	0.03
Serine	1.68	0.04
Tyrosine	0.89	0.01

[1]Expressed as percentage or unit of "as fed" sample.
[2]Expressed as percentage of air dry sample.

Addition of fats to a nutritionally complete diet often produces a slight increase in growth and always improves efficiency of feed utilization in monogastric animals. This is due to the higher caloric density of the fat-containing diet. However, benefits from fat alone can be obtained when amounts of all other nutrients in the diet are increased in proportion to the increase in energy level.

Several workers have reported that a higher level of cassava root supplement in diets of poultry and pigs depresses growth and feed efficiency (Oyenuga 1961; Castillo et al. 1964; Enriquez and Ross 1967; Olson et al. 1969a,b; Hew and Hutagalung 1972; Müller et al. 1972). Similar reports have been made on the supplementation of a large concentration of cassava leaves in rat, chick, and pig diets (Rogers and Milner 1963; Terra 1964; Ross and Enriquez 1969; Adrian and Peyrot 1970; Eggum 1970; Lee and Hutagalung 1972; Hutagalung et al. 1973, 1974). The reasons given for this growth depression, apart from the HCN content are: powdery characteristic of the roots; dry and loose texture of leaves; bulkiness of both leaves and roots; high ash content of the roots; and high crude fibre content of the leaves.

Growth depression of animals fed cassava-based diets was corrected by the addition of fats and oils (Hutagalung 1972; Hew and Hutagalung 1972; Lee and Hutagalung 1972). Fats and oils have been used extensively as sources of energy for feeding livestock. Within the last decade Malaysia imported substantial amount of fats (tallow and lard) from other countries (USA, Australia, New Zealand) as feed ingredients. However, in view of the high cost of these imported fats, the feed manufacturers have substituted these with local sources such as crude palm oil and one of its by-products stearin. Studies in pigs and poultry on the use of palm oil and stearin as an energy source have shown favourable responses in rate of gain and feed efficiency (Hutagalung 1972; Ng and Hutagalung 1974; Hutagalung and Chey 1975; Hutagalung and Chang 1977a,b). In terms of energy and digestibility, palm oil is superior to fats of animal origin (Table 2). The energy values of the roots and leaves have been evaluated (Hutagalung et al. 1973; Müller et al. 1974) (Table 3).

The improved performance of animals fed palm oil may be attributed to the increased energy intake. Faster rate of gain was obtained from the addition of palm oil up to 8% to the cassava or sago diet, beyond which a plateau occurred (Hew 1975).

Various sources and levels of fats and oils have been added to cassava-based diets. Supplementation of 5% palm oil to the 50% cassava-0.2% methionine diet improved the performance of pigs (Hew and Hutagalung 1972). Hutagalung and Chang (1977b) studied the effects of palm oil, stearin, lard, and tallow addition to a cassava-based diet on the performance and carcass quality of growing and finishing pigs. Supplementation of either palm oil or stearin within the range of 5–10% to a 30% cassava-based diet significantly improved the rate of gain and feed efficiency of pigs compared with those on the basal and the lard

Table 2. Nutritive value of animal fats and vegetable oils (NRA 1974).

	Melting point (°C)	Digestibility (%) in monogastrics	ME (kcal/g) in monogastrics	Avg. fatty acid content (%)		
				Saturated	Unsaturated	Linoleic acid
FGAF[1]	34–38	93	8.75	44	56	10
Lard	32–38	94	8.85	36	64	12
Poultry fat	28–35	96	9.00	28	72	25
All beef tallow	38–42	84	7.80	56	44	2
Palm oil	28–36	96	8.90	42	58	10

[1]Feed Grade Animal Fats are mixtures of poultry fat, lard, and beef tallow.

Table 3. Metabolizable energy values (ME, kcal/g) of cassava leaves and roots for livestock (on a dry matter basis).

	Roots	Leaves
Poultry[1,2]	3.23–3.65	1.59
Swine[1,2]	3.55–3.80	1.68
Sheep[2]	3.07	—
Cattle[2]	3.25	—

[1]Hutagalung et al. (1973, 1974); Hew (1975).
[2]Muller et al. (1974).

or tallow cassava-based diets. Carcass quality evaluation showed that palm oil or stearin addition at 5% to cassava-based diets produced better carcass quality compared with those on basal, lard or tallow supplemented diets (Table 4). Fatty acid composition of the tissues was studied and the results are being analyzed. Devendra and Hew (1977) fed pigs varying levels of palm oil (0, 5, 10, 20, 25, 30%) in diets containing cassava-root meal ranging from 10 to 24%. They found no apparent differences in rate of gain and feed efficiency due to levels of palm oil and cassava. With such a wide range of palm oil addition, carcass characteristics were not affected by either palm oil or cassava, even at the 30% palm oil level, except that the iodine value increased with increasing levels of palm oil supplementation. However, they suggested that the optimum level of palm oil inclusion in the cassava-based diet of pigs was 5%. Shimada et al. (1971) studied the effect of corn oil (0 vs. 3%) supplementation to cassava-based diets (30 vs. 60% cassava) in growing pigs. Supplementation of oil to cassava-based diet with or without methionine improved rate of gain and feed efficiency of pigs. Addition of corn oil was more effective in rate of gain and feed efficiency of pigs given diets containing a higher percentage of cassava. Fat from the carcasses of pigs fed cassava-soybean diets had a lower iodine number than those fed maize-soybean diets.

Using fat of animal origin, Maner (1974) reported that supplementation of 10% beef tallow to 55% cassava-meal diets of growing pigs with 0.1% methionine gave faster and more efficient feed conversion than those given cassava-based diets containing 0.1% methionine and cassava-based diets containing 0.2%

Table 4. Effect of levels of palm oil, stearin, lard, and tallow in 30% cassava-root based diets on the performance and carcass quality of growing and finishing pigs (Hutagalung and Chang 1977).

	Basal diet	Palm oil		Stearin		Lard		Tallow	
		5%	10%	5%	10%	5%	10%	5%	10%
Avg. daily gain (kg)	0.55	0.60	0.61	0.62	0.62	0.57	0.60	0.55	0.59
Avg. daily feed (kg)	1.62	1.80	1.68	1.90	1.71	1.84	1.78	1.91	1.82
Feed/gain	2.95	3.00	2.76	3.06	2.75	3.23	2.96	3.47	3.09
Dressing (%)	79.77	79.84	78.20	79.48	80.31	80.93	78.25	81.19	77.95
Carcass length (cm)	69.90	69.58	71.91	71.34	69.60	71.12	70.13	70.49	68.20
Backfat (cm)	2.34	2.27	2.40	2.33	2.38	2.37	2.57	2.35	2.50
L. dorsi area (cm^2)	28.2	29.5	29.3	27.9	29.0	28.6	27.8	28.0	26.5
Iodine number	58.1	59.3	61.0	59.0	60.8	57.6	52.7	53.6	54.3

methionine with no tallow added (daily gain: 0.85 vs. 0.80, 0.82 kg; feed/gain: 2.24 vs. 2.35, 2.47). It is interesting to note that addition of 0.2% methionine to 10% tallow-cassava-based diets did not improve gain or feed/gain of pigs compared with a similar diet without added methionine (0.74 vs. 0.85 kg; feed/gain 2.21 vs. 2.24).

Studies on the effects of fat and sugar supplementation in cassava-based diets showed that this combination was more effective in overcoming the growth depression. Montilla et al. (1975) supplemented 2% animal fat and 9% molasses to diets containing either 30% bitter or sweet cassava meal. They found that addition of fat and molasses to the 30% cassava-based diet did not improve rate of gain and feed efficiency of chicks, except in the diets with low cassava content. Palm oil (5%) and glucose (2%) addition to diets containing 50% cassava and 0.2% methionine further improved the performance of pigs compared with those on cassava-methionine diets without palm oil (Hew and Hutagalung 1972). Similar results were obtained with chicks by feeding 3.7% soybean oil and 4% molasses with the 50% cassava-based diet containing methionine, but not with cassava-based diet without added methionine (Enriquez and Ross 1967).

Ross and Enriquez (1969) reported that addition of both soybean oil and molasses to methionine-supplemented cassava leaf diet had no effect on gain and feed conversion of chicks. Supplementation of sucrose alone to the cassava-leaf diet of rats in an attempt to improve feed intake was not successful (Rogers and Milner 1963). On the other hand, molasses or palm oil added to the cassava-leaf diet improved rate of gain and feed efficiency of pigs. This improvement was accentuated by the addition of methionine (Lee and Hutagalung 1972; Hutagalung et al. 1973, 1974). Oke (1966) reported that addition of glucose to unprocessed cassava root meal caused the HCN to disappear.

Data on the carbohydrate composition and enzyme properties of cassava are rather limited. Lira and Fernandez (1962) reported that cassava flour has a high starch content that highly favours tryptic digestion. Johnson and Raymond (1965) indicated that cassava flour is mainly a polyglucose carbohydrate containing 20% amylose and 70% amylopectin. The amylolytic activity (amylase) of cassava root meal is about one-third of that in maize and about one-half of that in rice bran (Müller et al. 1974, 1975a). However, no data were given to substantiate this amylase activity. The detailed study of enzyme activity, and the carbohydrate and fatty acid composition of cassava roots and leaves in the fresh and dry condition are worthy of consideration for accurate assessment of their nutritive value.

Because cassava-based diets are low in fat, it has been suspected that essential fatty acids are limiting. Müller et al. (1975b) indicated that supplementation of essential fatty acids (by 2% peanut oil) to a 50% cassava-based diet did not affect rate of gain or feed efficiency (Table 5). Because fish meal, maize, and soybean were added to the cassava-based diets, it is plausible that these diets contained sufficient essential fatty acids prior to the addition of peanut oil.

Apart from being a principal source of energy, supplemented fats or oils also provide certain "additional dynamic actions" (ADNA), including increased growth, better palatability, essential fatty acids, better absorption or retention of other nutrients, and a significantly improved dust control (N.R.A. 1974, Table 2).

Improvements in rate of gain and feed efficiency of animals fed palm oil added to a cassava-based diet could be due to an improvement in palatability. Hutagalung (1972) postulated possible interaction between essential fatty acids present in the palm oil and the methionine of the diet. Furthermore, the addition of palm oil to cassava-based diet enables the animals to utilize methionine efficiently and to facilitate absorption and retention of essential fatty acids. Sugars (molasses/sucrose/glucose) in cassava-based diets probably reduce HCN levels by forming glyconohydrin, and as well improve palatability.

Protein and Amino Acids

Cassava root meal is low in crude protein and essential amino acids, with insignificant levels for methionine, cystine, and tryptophan (Table 1). Therefore, when it is used in large proportions, most of the protein in the diet must come from other protein sources. Similarly, when the maize fraction of the diet is replaced by cassava meal, the level of the protein source should be adjusted to balance the difference in the level of protein between maize and cassava. When soybean meal is used as the main protein supplement, growth

Table 5. Effect of supplementation of essential fatty acids, niacin, lysine, and methionine in cassava-based diets on the performance of broiler chickens (Müller et al. 1975b).

	Maize diet	Cassava-based diet (50% cassava meal)				
Fish meal (%)	6.0	10	10	10	5	5
Palm oil (%)	—	2	—	—	—	—
Peanut oil (%)	—	—	2	2	2	2
Niacin (mg/kg)	—	—	—	20	20	20
Lysine (%)	—	—	—	—	—	0.11
Methionine (%)	—	—	—	—	—	0.05
Performance at 10 weeks						
Live wt. (kg)	1.93	1.87	1.85	1.88	1.77	1.80
Feed/gain	2.65	2.78	2.81	2.76	2.88	2.78
Mortality (%)	11.0	10.1	14.1	11.1	5.10	2.00

depression is more likely to occur than in the case of a protein supplement of animal origin, such as fish meal. This is because methionine is the first limiting amino acid in soybean protein (Kroening et al. 1965; Berry et al. 1966).

Cassava leaves could become a potential source of protein for human and livestock (Rogers and Milner 1963; Terra 1964; Ross and Enriquez 1969; Eggum 1970; Lee and Hutagalung 1972; Adrian and Peyrot 1971; Hutagalung et al. 1973). Leaf-protein concentrate could be used as a protein supplement for monogastrics and the voluminous-fibrous residue could be utilized as roughage for ruminant animals (Nestel 1974, 1975; Müller et al. 1975a). The protein content of cassava leaves is 17–40%, depending mainly on age and time of harvest, variety, soil condition, and processing methods (Rogers and Milner 1963; Eggum 1970; Hutagalung et al. 1973) and their nutritive value is somewhat similar or even superior to alfalfa leaf meal (Bangham 1950). The protein of cassava leaves is deficient in sulfur-containing amino acids (methionine and cystine), marginal in tryptophan and isoleucine, but rich in lysine (Akinrele 1967; Hutagalung et al. 1973; Müller et al. 1975a). Digestibility of the protein in cassava leaves was shown to be high, especially with young leaves (Van Veen 1938; Luyken et al. 1961). Young leaves had a true digestibility of 80% for the protein but this decreased to 67% in older leaves (Luyken et al 1961). Methionine addition to older leaves increased net protein utilization (NPU). Eggum (1970) reported that digestibility of leaf protein in rats was from 70 to 80%; whereas, its biological value was 44–57%, depending on the methionine content. He stated further that only about 60% of its methionine was available and that the true availability of the other amino acids was inconsistent.

Hew and Hutagalung (1972) observed growth depression in pigs as the level of cassava root in the diet increased. In their study, animal protein was kept constant, while vegetable protein was increased with increasing level of cassava. On the other hand, when the level of animal protein (fish meal) was raised and the plant protein was held constant, the growth depression of pigs fed cassava-based diet was alleviated (Hew and Hutagalung 1972, 1976) (Table 6). Reports elsewhere have also shown that supplementation of high quality protein feedstuffs to cassava-root based diet could overcome growth depression (Maner and Gomez 1973; Khajarern and Khajarern 1976). Reduction of fish meal from 10 to 5% in the 50% cassava-based diets resulted in a significant reduction in growth rate and less efficient feed conversion of broiler chickens (Müller et al. 1975a).

Phuah and Hutagalung (1974) studied the effects of varying protein increment (19–17; 22–20; 25–23%) in combination with graded levels of cassava root meal (0, 20, 40%) on the performance and body composition of broiler chickens. Protein and cassava levels in the diet gave little or no improvement in rate of gain and feed efficiency. The nonsignificant response of chicks apparently was due to the fact that the diets were balanced in animal and plant proteins to supply the essential amino acids. However, increasing levels of dietary protein in the cassava-based diet resulted in increased carcass protein and decreased carcass fat (Table 7).

Supplementation of groundnut flour, skim

Table 6. Effect of fish meal supplementation to diets containing 18% soybean meal and varying levels of cassava on performance and carcass measurements of pigs (Hew and Hutagalung 1976).

	Cassava (%)				
	0	15	30	45	60
	Fish meal (%)				
	9	11	13	15	18
Avg. daily gain (kg)	0.62	0.58	0.58	0.60	0.63
Avg. daily feed (kg)	2.10	2.02	2.07	1.98	2.11
Feed/gain	3.40	3.45	3.60	3.32	3.38
Days to slaughter	113	109	109	112	114
Dressing (%)	78.33	79.18	80.40	79.85	78.63
Shrink (%)	3.22	4.59	4.35	4.17	4.02
Backfat (cm)	2.48	2.33	2.26	2.54	2.57
L. dorsi area (cm^2)[3]	32.28	33.50	36.59	31.93	32.83
L. dorsi area (cm^2)[4]	18.17[1]	17.44[1]	15.63[1,2]	13.90[2]	14.25[2]

[1,2]Means in the same row bearing different superscripts differ significantly ($p < 0.05$).
[3]*L. dorsi* area taken at 2nd lumbar position.
[4]*L. dorsi* area taken at 4th rib position.

Table 7. Effects of dietary cassava (C) at levels of 0, 20, and 40% and protein on performance and body composition of broiler chickens (Hutagalung et al. 1973; Phuah and Hutagalung 1974).

	19–17% protein			22–20% protein			25–23% protein		
	0% C	20% C	40% C	0% C	20% C	40% C	0% C	20% C	40% C
Av. daily gain (g)	18.0	17.5	16.8	18.6	12.6	16.1	18.1	17.6	16.7
Feed/gain	2.42	2.19	2.31	2.10	2.09	2.24	2.15	2.24	2.20
Whole carcass									
Moisture (%)	65.3	68.3	67.8	68.7	69.6	70.4	69.2	69.8	68.4
Fat (%)[1,2]	32.8	25.6	25.8	23.9	23.9	18.5	16.4	16.1	21.0
Protein (%)[1,2]	52.1	57.4	57.5	59.4	60.7	61.0	64.3	67.1	63.2

[1]Significant ($p < 0.01$) effect of cassava and protein.
[2]Significant ($p < 0.01$) cassava × protein interaction.

milk powder, or a mixture of the two to the cassava-based diets, to provide 15% extra protein, resulted in a significant increase in the growth rate of rats compared with those on cassava-maize diets (Tasker 1962). Barbosa et al. (1957) substituted wheat flour by a combination of cassava and peanut-oil meal in swine diets and found that rate of gain and feed efficiency were superior in the cassava-peanut-oil-meal diet.

Eggum (1970) compared the combination of dried fish (cod) and cassava leaves in rats and found a marked improvement in the biological value of leaf protein.

Hew and Hutagalung (1976) stated that the choice of cassava root meal with a low cyanogenic glucoside content and the use of high quality proteins to correct nutrient deficiencies, such as sulfur-containing amino acids and vitamins, make the replacement of grains by cassava possible. The inclusion of a higher concentration of fish meal as animal protein rather than a combination of plant protein and synthetic amino acids compared favourably in terms of rate of gain, feed efficiency, and the cost of feed per unit of gain (Table 6). The use of a higher quantity of fish meal may have improved the protein quality or the amino acid make up of the feed and hence supported better growth. Also, fish meal is a rich source of vitamin B_{12} that may contribute to the detoxification process of HCN. In the case of a cassava-fish meal combination, methionine supplementation may not be required. However, where fish meal is limited and expensive, methionine supplementation of a combination

of cassava and plant protein would be more economical.

Amino Acids

The role of methionine addition to cassava-based diets has been presented by Adegbola (1977). Therefore, this discussion is confined only to amino acids other than methionine. It has been generally agreed that supplementation of sulfur-containing amino acids in cassava-based diets serves two functions. Besides satisfying the overall essential amino acid requirement of the animals, methionine in particular is actively involved in cyanide detoxification. Sulfur-containing amino acids contribute the sulfhydryl (–SH) groups that react with cyanide to form harmless thiocyanate. The sulfhydryl group is also supplied by 3-mercaptopyruvic acid, which may arise from cystine by transamination or deamination (Meister 1953).

Literature on supplementation of synthetic amino acids other than methionine to cassava-based diets is rather limited, particularly for large animals. One would expect a scarcity of nutritional studies on these essential amino acids. Commercially, lysine, methionine, and occasionally cystine are the only amino acids available at reasonable cost. Other amino acids such as tryptophan and threonine are produced on a laboratory scale, and for large scale application they are very costly. Hence, most of the work on amino acid supplementation to cassava-based diets has been done on small animals.

Earlier work on amino acid supplementation in chickens (Enriquez and Ross 1967) indicated that the adverse effects of a high cassava (50%) diet were overcome by supplementation with 0.15% methionine. Similarly, Olson et al. (1969b) obtained satisfactory results with supplementation of 0.2–0.8% methionine or 0.4–0.8% cystine in cassava (45%) diets. The role of cystine to replace methionine, ranging from 40–70% has been documented (Becker et al. 1955; Baker et al. 1969; Mitchell et al. 1968).

Work in Malaysia and Singapore has also demonstrated the ability of sulfur-containing amino acids to alleviate the depressing effects of high cassava rations given to pigs (Hutagalung 1972; Hew and Hutagalung 1972; Müller et al. 1972; Hutagalung et al. 1973) and poultry (Kassim and Jalaludin 1972; Leong and Jalaludin 1972; Oh and Jalaludin 1972; Chou and Müller 1972; Hutagalung et al. 1974; Syed et al. 1975; Yeong and Syed 1976a,b).

Olson et al. (1969a,b) studied the effects of leucine or methionine (or both) supplementation to rations containing 45% cassava meal in chicks. Addition of 0.1% methionine, but not 0.1% leucine, to the cassava-based diets increased weight gain and feed efficiency. Supplementation with both leucine and methionine resulted in significantly heavier birds and better feed conversion compared with unsupplemented diets and those receiving only leucine.

Incorporation of both lysine (0.11%) and methionine (0.05%) into 50% cassava-based diets containing 2% peanut oil and 5% fish meal markedly improved rate of gain and feed conversion of broiler chickens during the early period but not at 10 weeks of age (Müller et al. 1975b) (Table 5). It appears that the addition of lysine and methionine was necessary for the chicks to reach optimum growth; whereas, at 10 weeks of age these higher levels were not required.

Lysine and methionine supplementation to cassava-leaf based diets increased the protein efficiency of rats (Pechnik and Guimares 1962). Drying, prolonged cooking, and re-drying of the leaves had no significant effect on the growth of rats even when supplemented with lysine, methionine, and threonine. In a subsequent experiment (Pechnik and Guimares 1963) lysine, histidine, and methionine addition, singly or in combination, to sweet cassava-leaf based diets gave various growth responses in young rats. Methionine alone gave the best growth response; whereas, the addition of lysine and histidine resulted in decreased feed efficiency and body weight gain. No explanation was given for this growth depression, but it could be due to an amino acid imbalance in the protein of the leaf.

The effectiveness of adding amino acids, especially those belonging to the sulfur-containing group, to alleviate growth depression depends primarily on the level and source of protein and energy in the cassava-based diets. However, one can question the safety of adding synthetic amino acids to the diet. Eggum (1970) indicated the possibility of an adverse effect from an overdose of single amino acids. In an extensive review by Harper et al. (1970), it was stated that excessive intake of individual amino acids, particularly in young animals fed a low protein diet, can result in adverse effects ranging from moderate growth and

food intake depression to clear-cut toxic reactions. Amino acid imbalance and more general dietary disproportion, result in depressed food intake and growth. They further stated that methionine is the most toxic of the amino acids, and that in amounts exceeding 2% of the diet it causes severe growth depression and histopathological changes. Excessive intake of lysine, arginine, leucine, isoleucine, and valine appears to be mutually antagonistic. This antagonism appears to be due to the specific structure and metabolic relationships of the individual amino acids. The adverse effects are generally alleviated if the protein content of the diet is increased or the nutritional quality of the protein is improved. Therefore, when supplementation of synthetic amino acids to cassava-based diets is required the amino acid balance and the protein and energy contents of the diet should be carefully considered.

Nonprotein Nitrogen

It is known that nonprotein nitrogen (NPN), mainly urea, in ruminant animals can satisfactorily replace up to 25% of the total dietary protein (Reid 1953). However, there is evidence that the growth of animals on such diets is slightly depressed in comparison with those on conventional protein. Addition of urea beyond 1% of the ration often reduces palatability, but this can be counteracted by molasses. With the shortage of conventional protein, grains, or forage concentrates, the use of urea with either cassava or molasses, or both, as protein and energy sources, has been frequently practiced, more so in ruminants than in monogastric animals.

Little work has been done on the use of cassava products, particularly leaves, as ruminant feeds. This is probably due to the difficulty of obtaining sufficient quantity of cassava materials for feeding experiments, notably for beef and dairy cattle. Chicco et al. (1971) and Schultz et al. (1970a,b) undertook extensive studies on the effect of feeding a combination of cassava and urea to cattle and sheep. Chicco et al. (1971) evaluated the effect of urea (1%) and molasses (5%) added to the cassava-based diet on the digestibility and rumen constituents of sheep. Significant improvement with the urea-molasses-cassava combination was observed for bacterial protein, blood urea, propionic acid, butyric acid, and for the digestibility of organic matter and cellulose. Schultz et al. (1970a) compared the effects of adding urea to either uncooked or cooked cassava with vegetable protein in cattle. Addition of urea to cooked cassava improved the quantity of microbial N and total volatile fatty acid (VFA) concentration, but not ruminal cellulose digestion, compared with uncooked cassava. In their following experiment (Schultz et al. 1970b), urea-cassava-molasses diets were compared with a vegetable protein control diet in young cattle. Rumen microbial protein content of the control diet was higher than that of the cassava-urea and molasses-urea combination; whereas, VFA concentrations in the rumen samples from rations containing urea were equal to or greater than the control diet. No apparent differences were noted for cellulose digestibility in the rumen. Somewhat similar studies on urea-cassava utilization in cattle were reported by Kay et al. (1972) and Karue et al. (1973). Karue et al. (1973) fed poor quality hay supplemented with concentrates containing cassava, molasses, and urea to Zebu steers. They found that an increase in caloric intake from the cassava concentrates resulted in reduction of metabolic body weight of the steers. Müller et al. (1975a) indicated that feeding cattle, either in a feedlot or on pasture, a concentrate diet containing 85% cassava root meal, 6% molasses, 8% urea, and 1% mineral supplement compared favourably with tropical grasses for optimum performance. However, no data were given in recommending such a combination, especially when the urea used was higher than is normally recommended.

Substitution of corn by 1.5% urea in a chopped sugarcane foliage-cassava diet produced similar weight gains of 8-month-old heifers (Pineda and Rubio 1972). Total or partial substitution of cotton seed meal by urea in the diet, when cassava was used as a supplement, produced similar weight gains. A marked increase in weight gains was obtained when cassava was used as a supplement in a molasses-urea mixture (Neves 1969).

There have been some attempts to use the wastes from the poultry industry as nitrogen sources for livestock. Ng and Hutagalung (1974) studied the effects of poultry excreta (5, 10, 15%) in combination with two levels of cassava (15, 30%) diet containing either low (17–19%) or high (20–22%) protein levels in broiler chicks. Supplementation of 15% poultry excreta to a 30% cassava-based diet produced no adverse effects on perform-

ance. Müller et al. (1975a) indicated that the addition of poultry excreta to cassava-based diets produced responses in broiler chickens similar to those from maize-soybean diets. With recycling technology, they have successfully and economically fattened steers in Singapore on a ration composed of 60% cassava meal and 38% poultry litter.

One should take into consideration when using animal wastes, that they are very variable. Their major disadvantage seems to be a reduction in palatability, but there is also the problem that drugs previously administered to the poultry might prove toxic to animals fed poultry wastes.

Minerals

Most of the work reported earlier on mineral-cassava relationships in domestic and laboratory animals has been concerned with mineral deficiency, particularly iodine (Ekpechi et al. 1966) and zinc (Maust et al. 1969, 1972), rather than their effect on economic criteria such as growth rate and feed conversion.

Recent investigations, however, have been directed to the effects of mineral-cassava combinations on mineral metabolism and the performance of animals (Ermans et al. 1973; Maner and Gomez 1973; Phuah 1973/74; Hutagalung and Tan 1976; Phuah and Hutagalung 1977). In view of the fact that minerals are relatively inexpensive resources and represent only a small part of the diet, there has been little incentive to carry out extensive studies on the effect of mineral supplementation of cassava-based diets on performance, especially for large animals. Moreover, interactions of minerals with each other, especially of the trace elements, present problems of interpretation.

Calcium (Ca) and Phosphorus (P)

The calcium and phosphorus contents of cassava roots used in Malaysia (Table 1) are relatively high (Ca 0.35%; P 0.40%) (Hutagalung et al. 1973); whereas, reports from Africa (Oke 1966) show lower values (Ca 0.13%; P 0.15%). However, contents of other minerals are low, principally copper, iron, and zinc (Raymond et al. 1941; Oke 1966; Maust et al. 1972; Hutagalung et al. 1973). Particular attention should be given to the oxalic content of the cassava root, which is reported to range from 0.1 to 0.32% (Raymond et al. 1941; Oke 1966), because this affects the absorption of minerals. Variations in the mineral content of cassava root meal could be due to variations in total ash content, which are affected by the rate of contamination by soil and foreign materials during harvesting and drying.

Zinc (Zn)

Hutagalung (1972) demonstrated that pigs fed diets containing a high level of cassava root (60–75%) developed distinctive disorders such as diarrhea, skin lesions on the mucosa of the mouth, stomach, and hind quarters, localized swelling and hind leg weakness, and watery meat. Some of these conditions were also observed in chickens (Phuah 1973/74). Low copper (Cu) and Zn contents of the tissues of chicks fed cassava root diets tend to indicate that cassava could upset the balance and availability of minerals (Hutagalung et al. 1973).

Utilization of a large quantity of cassava meal in livestock has resulted in poor gains and parakeratosis, but this condition is corrected by adding extra Zn to the diet (Maust et al. 1969, 1972; Hutagalung et al. 1973; Phuah 1973/74). An explanation for the Zn-cassava relationship is not apparent, especially when the Zn level in the diets was calculated to meet the recommended requirement (NRC 1973). Generally, the incorporation of a large quantity of cassava into the diets necessitated the addition of a greater amount of protein, such as soybean meal, to satisfy protein requirements. When additional soybean is used the phytic acid level in the diet is proportionally raised, resulting in reduced absorbability of Zn from the intestine because more Zn is involved in the formation of insoluble Zn-phytate (Savage et al. 1964; Edwards 1966; Hutagalung et al. 1977). The relatively large quantity of calcium (Ca) in cassava and fish meal, and the presence of oxalic acid in the cassava root, might also reduce the availability of Zn. The presence of Ca in excess was reported to aggravate Zn depletion in the intestine by raising the intestinal pH (Oberleas et al. 1966), and the addition of Zn to the diet might replenish Zn bound to the insoluble Ca-Zn-phytate complex (Savage et al. 1964; Edwards 1966). Hutagalung et al. (1973) stated that an improvement from Zn addition could be attributable to Zn participation in carbohydrate metabolism in that Zn increased the glucose uptake by adipose tissues.

Iodine (I)

In the presence of marginal I and low protein intake, high levels of cassava in the diet may be a key factor in the development of goitre and cretinism (Ekpechi 1973; Ermans et al. 1973) and possibly the cause of reduced availability of zinc (Maust et al. 1972). Apart from Zn deficiency, animals fed diets containing a high concentration of cassava have been suspected to suffer I deficiency (Ekpechi 1973; Hutagalung et al. 1973; Maner and Gomez 1973). Supplementation of I can reduce the deleterious effect of cyanide toxicity, which is manifested as subnormal thyroid function or goitre (Ekpechi et al. 1966) and ataxic neuropathy (Osuntokun 1973). The goitrogenic action of cassava is well documented by Ermans et al. (1973). They stated that the main effect of prolonged consumption of cassava is a marked depletion of the thyroidal I stores, which appears to be severe in the absence of I supplementation. Consequently, animals fed diets containing a large proportion of cassava require a constant supply of I to maintain the thyroid function.

In contradiction to findings in rats (Maner and Gomez 1973; Ekpechi 1973), studies in Malaysia have shown that rate of gain and feed efficiency of broiler chicks were not significantly affected by an I level up to 50 mg/kg (Hutagalung et al. 1973; Phuah 1973/74). Similarly in pigs it was observed (Hutagalung and Tan 1976) that addition of I up to 100 mg/kg to cassava-based diets had no apparent effect on growth and feed efficiency, but addition of 500–1000 mg/kg I depressed growth and feed intake of pigs, rats, and poultry. No significant differences in the carcass composition of pigs resulted from supplementing I in cassava based diets. Iodine (I^{131}) uptake by the thyroid gland decreased with a higher increment of I, particularly at the 50 and 100 mg/kg supplementation levels. The nonsignificant effect of I supplementation could be attributed to the low HCN content of the cassava-based diets. Ekpechi et al. (1966) reported an increased uptake of I^{131} by the thyroid after cassava (50–100%) or I-deficient diets were fed to rats; uptake was normal after I addition. They suggested that the cassava diet was not only I-deficient but also contained a goitrogen. Iodine uptake is energy dependent and is inhibited by cyanide. In their investigation, Maner and Gomez (1973) suggested that because cyanide detoxification requires labile sulfur methionine could serve as a source of sulfur. The detoxification produces thiocyanate, which exerts a goitrogenic effect on the body resulting in thyroid hypertrophy, especially in the absence of adequate dietary I (Sihombing et al. 1974; Cromwell et al. 1975). The extent of supplementation also deserves particular attention because excessive intake of I can cause further problems, including cessation of egg production, delayed sexual maturity, altered reflexes, and diarrhea (Arrington et al. 1967; Wilson et al. 1967; Wilson and Harms 1972; Wilson and Rowland 1970; Phuah 1973/74).

Iron (Fe)

Iron supplementation in cassava-based diets should be undertaken only when there is a deficiency. This is because excessive Fe in the diet can cause nutritional disturbance of P by forming insoluble phosphate, which results in reduced P absorption (Harmon et al. 1968; Standish et al. 1969).

Cobalt (Co)

Cobalt is required for the biosynthesis of vitamin B_{12}; therefore, in a cassava-based diet, Co indirectly plays a part in the cyanide detoxification. The simple salts of Co readily combine with cyanides to form a stable, harmless ion, cobalt cyanide $Co(CN)_6$ (Knowles and Bain 1968).

Selenium (Se)

Selenium functions to ensure efficient utilization of vitamin E or to serve as a nonspecific antioxidant (Oldfield et al. 1963). However, because of its low requirement and its toxicity when used improperly, Se should be used as a feed additive only under careful supervision.

Other Minerals

Other trace minerals likely to be important in the formulation of cassava-based diets are copper (Cu), magnesium (Mg), and manganese (Mn). Under normal conditions, all these trace minerals are easily provided by supplementing the diets with the proper proportion of premixed trace minerals. In cases of deficiency of one or more elements, particular attention should be directed to the antagonistic effect of elements supplemented together. Zinc, particularly when added as an inorganic salt to cassava-based diets, in an attempt to alleviate parakeratosis symptoms, can depress Cu ab-

sorption and retention. This antagonism is most prominent when Cu is limiting, leading to acute Cu deficiency (Van Campen 1966; Phuah 1973/74). Starcher (1969) attributed the depressing effect of Zn on Cu absorption to competition for an active site in the duodenal mucosa protein, which serves to transport these elements during absorption.

Vitamins

Besides being deficient in protein, fat, and trace minerals, cassava roots are also low in vitamins. Vitamin A content is only a trace, thiamine 0.6 mg/kg, riboflavin 0.3 mg/kg, and niacin 0.6 mg/kg. De Brochard et al. (1957) reported the vitamin content of cassava root meal to be: vitamin A 550 IU/kg; vitamin D_3 0.01 IU/kg; thiamine 1.6 mg/kg; and riboflavin 0.8 mg/kg. In fresh roots, vitamin values given by different workers are variable; thiamine levels were found to be 0.4–0.6 mg/kg (Jones 1959; Chadha 1961; Müller et al. 1972), but riboflavin values were 0.75 mg/kg (Müller et al. 1972) or lower 0.3 mg/kg (Chadha 1961; Jones 1959). Ascorbic acid in fresh roots ranges from 5 to 360 mg/kg (Raymond et al. 1941; Chadha 1961; Müller et al. 1972), but this is destroyed during the drying process.

Fresh cassava leaves contain high levels of ascorbic acid (0.4–1.8 g/kg), appreciable amounts of the B-vitamins and carotene, but very low levels of vitamin E (Raymond et al. 1941; Oke 1966).

The vitamin values of the cassava root are nutritionally insignificant compared with those of maize. Therefore, to substitute maize with cassava meal in the formulation of the diet, vitamin values must be adjusted to meet the requirements. Vitamin A is particularly critical because yellow maize in a normal diet contributes adequate amounts of vitamin A in its precursor form (carotene and cryptoxanthine). The vitamin A content of cassava root meal is particularly low and this vitamin is readily destroyed by exposure to air and light, especially during the drying process when it is exposed to high temperatures.

Of the B-vitamins, niacin (nicotinic acid) and vitamin B_{12} (cyanocobalamin) deserve particular attention. Niacin in cereal grains and their by-products is unavailable to monogastric animals as it is present in a bound form (Scott et al. 1969). The presence of a sufficient quantity of tryptophan in the diet can reduce the need for niacin, due to the ability of animals to synthesize niacin from tryptophan. Because tryptophan and other essential amino acids are deficient in cassava root meal, supplementation of niacin in the cassava-based diets is inevitable. However, the addition of 20 mg/kg niacin to 50% cassava-based diets has no apparent effect on the rate of gain and feed efficiency (Müller et al. 1975b). The fish meal content of the diet ranged from 5 to 10%; therefore, it is possible that the tryptophan content of the diet was sufficient to meet the tryptophan and niacin requirements (Table 5).

Because biotin synthesis depends on the availability of sulfur and sulfur-containing amino acids, biotin deficiency is likely to occur in cassava-based diets low in methionine. Biotin addition (0, 50, 100 μg/kg) to either 65% broken rice-35% cassava diet or 57% cassava-based diet did not exert any improvement in the performance of chicks (Müller et al. 1975b). On the other hand, when biotin was supplemented to either 68% cassava-16% protein diet or 55% cassava-22% protein diet, it markedly improved body weight and feed efficiency of broilers, particularly with the low protein (16%)-55% cassava diet (Table 8). Unfortunately, these investigations did not state the composition of the diets, i.e. the type of ingredients used, level or source of protein and energy, kind of vitamins and minerals supplemented, which could have influenced the utilization of biotin.

Data on supplementation of other B-vitamins to cassava-based diets are very limited. Low plasma levels of riboflavin were reported in patients subsisting mainly on a cassava diet (Osuntokun 1972, 1973). Vogt and Penner (1963) reported that supplementation of an admixture of niacin, calcium pantothenate, and choline chloride to a 20–30% cassava-based diet did not improve gain or feed conversion of broiler chicks. Carvalho et al. (1969) observed an incidence of perosis in broiler chicks when a large proportion of wheat bran was substituted by cassava meal in the diet. This deficiency symptom was corrected by choline supplementation to the diet.

Vitamin B_{12} has been reported to be an important detoxifying agent in cyanide toxicity (Smith 1961). It was shown that mice exhibiting complete respiratory arrest and coma due to cyanide poisoning recovered rapidly after an injection of vitamin B_{12} (Mushett et al.

Table 8. Effect of biotin supplementation to low and high protein (P) cassava diets for broilers (Müller et al. 1975b).

Periods (weeks)	Added biotin (μg/kg)	Body wt. (kg)		Feed/gain	
		16% P	22% P	16% P	22% P
4th	0	0.44	0.60	2.18	1.64
	50	0.48	0.62	2.01	1.63
	100	0.50	0.60	1.89	1.67
6th	0	0.70	0.87	2.53	2.18
	50	0.64	0.96	2.33	2.04
	100	0.78	0.91	2.29	2.12

1952). The antidotal action of B_{12} results from the immobilization of the cyanide ion as harmless cyanocobalamin (B_{12}) (Smith et al. 1963). Likewise, cyanide poisoning has been shown to be aggravated by vitamin B_{12} deficiency (Wokes and Pickard 1955; Oke 1973).

The biological significance of the interrelationship between vitamin B_{12}, cyanide, and thiocyanate is not yet fully understood. It is believed that cyanide participates in normal metabolic processes (Boxer and Rickards 1952), and it is known to combine with various forms of B_{12} to form cyanocobalamin (Montgomery 1969). Chronic administration of cyanide to animals depletes liver B_{12} (Braekkan et al. 1957). An increase in urinary excretion of thiocyanate in vitamin B_{12}-deficient people can be counteracted by administration of large doses of the vitamin (Wokes et al. 1955).

Two hypotheses have been advanced to explain the role of vitamin B_{12}. Firstly, the cyanide utilization hypothesis assumes that rhodanese and hydroxocobalamin compete for cyanide, some of which converts hydroxocobalamin to its cyano-form, the latter splitting again thus regenerating hydroxocobalamin while the cyanide carbon enters one-carbon metabolism to be directly oxidized to carbon dioxide (Boxer and Rickards 1952). The weakness in this hypothesis is that it cannot account for the quantitative aspect of the observed facts. Secondly, the sulfur transfer hypothesis, based on the abundance of thiocyanate relative to cyanide in body tissues. In the presence of the large excess of thiocyanate, hydroxocobalamin may take up thiocyanate to form thiocyanacobalamin, which reverts to cyanocobalamin, liberating sulfur to an active intermediate X to form SX. The cyanocobalamin then completes the cycle by regenerating hydroxycobalamin, while the cyanide thus liberated is converted to thiocyanate by rhodanese (Oke 1973; Oh 1976).

Another problem with feeding large quantities of cassava meal to animals, particularly cassava chips, is the production of pale, soft, and exudative (PSE) meat. Addition of vitamin E in the form of DL-α-tocopheryl acetate above the recommended requirement can improve the meat quality (personal communication with researchers, feed manufacturers, farmers and butchers in Malaysia). The role of vitamin E in the prevention of muscular dystrophy is well documented, but its function in myoglobin synthesis is unknown. Meat colour is determined by the myoglobin content of the meat. There may be some factors in cassava meal that affect the absorption or metabolism of vitamin E in animals; however, little work has been done along this line. Investigation of the vitamin E-cassava relationship, when cassava is to be utilized as the main source of energy in the animal industry, is worthy of consideration.

Nonnutritive Feed Additives

Nonnutritive feed additives are included in feeds to ensure that the dietary nutrients are ingested, digested, protected from destruction, absorbed, and transported to the body cells, and frequently to alter the metabolism of the animals in an attempt to produce better growth or more desirable finished products. These include pigments (carotenoid sources), antibiotics and antifungals, flavouring agents, antioxidants, enzymes, hormones, pellet binders, coccidiostats and worming drugs, and tranquilizing agents.

Very little information is available on the effects of adding nonnutritive feed additives to cassava-based diets for livestock.

Pigments

Poultry farmers and feed manufacturers have been concerned that if their broilers and pullets were fed cassava-meal based diets, consumers would be reluctant to purchase them, because they would appear to lack in vigour or might produce pale skins, shanks, beaks, and egg yolks. They have usually added grass or legume (alfalfa) meals to corn-based diets to provide pigments (xanthophylls) for the skin and the egg yolks.

Two synthetic carotenoids have been tested widely as supplements for broiler and egg yolk pigmentation (Scott et al. 1969; Guenther et al. 1973; Hinton et al. 1974). These are marketed under various names, but essentially they are cantaxanthin and the ethylester of β-apo-8'carotenoic acid (BACE). Cantaxanthin, a red pigment, when added at 2–10 g/tonne of feed, supplements the natural xanthophylls for broilers; whereas, BACE at 2–8 g/tonne of feed, supplements the natural pigments of the laying mash to produce egg yolks of good colour. It would therefore be beneficial for a poultry farmer to know what effects xanthophyll supplementation to a cassava-based diet would have on subsequent yolk colour, and how much of the pigments are deposited in the fat and skin of broilers.

The effect of feeding cassava-based diets on the pigmentation of the skin, shanks, and fat of broilers (Yeong and Syed 1976a) and egg yolks (Hutagalung 1972; Syed et al. 1975; Yeong and Syed 1976b) has been demonstrated. The lack of pigmentation is attributed to the replacement of yellow maize (rich in xanthophyll) with cassava root meal. However, the defect in cassava rations can easily be corrected by the addition of synthetic carotenoids (Hutagalung et al. 1973; Syed et al. 1975; Yeong and Syed 1976a,b), or even by cassava leaves (Hutagalung and Chang 1977a). Agudu (1972) compared cassava and Madras thorn (*Pithecellobium dulce*) leaf meals, a synthetic xanthophyll material, and two sources of yellow corn as sources of egg yolk pigments in pullets. Xanthophyll assays showed that cassava leaf meal had a higher total and pigmenting xanthophyll content than Madras thorn leaf meal. Increased leaf meal in the diets resulted in increased yolk score, which was not proportional to the level of leaf meal in the diets. The commercial xanthophyll material had an unusually low xanthophyll content and consequently had no significant effect on yolk colour when supplemented at twice the recommended level to a white or yellow corn diet.

In pigs and other livestock, colour pigment is not normally included in the formulation of rations. However, many consumers feel that white fat on pork and beef has more eye appeal than a yellow fat; therefore, the addition of pigments in this case would be uneconomical. The colour of the feed containing large amounts of cassava is poor and less attractive, more so to the farmers than to the animals; in this case, some nonpoisonous colour agent or dye could be introduced.

Antibiotics and Fungicides

Cassava root meal has been implicated in problems of aflatoxicity, because it appears to be an excellent growth medium for aspergilli, especially *Aspergillus flavus*. Samples of cassava flour/starch/meal in Thailand, Hongkong, Brazil, India, and Uganda (Boshell 1968; Shank et al. 1972; Natarajan et al. 1973; Serck-Hanssen 1970) have been shown to contain mycotoxins (aflatoxins). Prolonged storage of high moisture cassava, the amount of free sugars available, and contamination with soil appear to induce the growth of *A. flavus*; whereas, in cassava with a low moisture content, the presence of aflatoxins is practically insignificant.

Schmidt (1966) analyzed 50 cassava food products of different origin and found a high level of bacteria and fungi, including *A. flavus*, *A. fumigatus*, *A. chevalieri*, *A. terreus*, and *Penicillium rubrum* which cause mycoses. He indicated that the chips were highly contaminated by soil containing these microorganisms.

In experiments with mouldy corn, Hew (1975) demonstrated that the presence of aflatoxin in the cassava and maize caused growth depression and less efficient feed conversion of pigs and rats. Oral administration of antibiotics and fungicids did not alleviate the adverse effect upon the chickens of the mycotoxin present in the feedstuffs. Hew (1975) added antibiotic two-fold higher than recommended to a cassava based pig diet suspected to be contaminated by aflatoxin. A slight improvement in the performance of the pigs was observed.

Although feeding diets based on high levels of cassava have been reported to cause diarrhea, there is no report to indicate the requirement of an antibacterial feed additive as a corrective measure. Also, there have been no

reports to demonstrate whether this condition can be corrected by drugs. In West Germany, cassava meal has been removed from turkey rations because it caused profuse watery diarrhea and was disastrous to the turkey industry (Fraser 1973). Because such a drastic measure has been taken, one can assume that the deleterious effect of cassava meal on turkeys could not be corrected by pharmaceutical means. With other livestock like pigs and chicken, the diarrhea did not appear to be very serious, probably due to their genetic potential to cope with cassava, which is evidently incompatible with the intestine of the turkey (Zausch et al. 1968).

Of the bacteria and fungi, *A. fumigatus* is the most pathogenic fungus and is the mould most frequently encountered in aspergillosis in chickens. The occurrence of bacteria and fungi would probably justify the addition of antibiotics and fungicids to cassava-root based diet.

Flavouring Agents

The ability of pigs and chickens to differentiate by showing preference for sucrose solution and rejection of saccharine solution has been demonstrated (Jacobs and Scott 1957). Kare (1965) also showed that chickens possess a sense of taste but a very limited ability to smell. However, experiments on supplementation of flavouring agent in a well-balanced diet did not appear to produce any significant increase in feed consumption (Kare 1965). Phuah et al. (1974) studied the effects of supplementing flavouring agents to cassava-based diets of broiler chickens. Addition of either an artificial flavouring agent or molasses did not improve the rate of growth or feed conversion of the broilers.

Whether chickens avoid certain feedstuffs on the basis of taste, lack of eye appeal, or because of adverse effects upon metabolism or "sense of well being" is unknown.

In pigs, the supplementation of normal rations with a flavouring agent (e.g. pig nectar) has been practiced by most feed manufacturers, especially in their starter and grower rations. In the case of cassava-based diets, the inclusion of a sweetener like glucose and molasses has been shown to increase appetite (Hew and Hutagalung 1972; Hutagalung et al. 1973) but without necessary improvement in growth and feed efficiency. As mentioned earlier, glucose and the glucose portion of molasses may play an active part in reducing the HCN content of the cassava by formation of glyconohydrin in addition to increasing the palatability of the cassava-based diet (Hew and Hutagalung 1972).

Enrichment of Cassava by Microbial Fermentation

The concept of fermenting cassava for human consumption is not a recent innovation. For many decades, various forms of fermented cassava such as peuyeum and gari have constituted a part of the staple diet of the people in Asia and Africa (Hesseltine 1965; Gray 1970; Pederson 1971). However, the idea of employing microorganisms to convert cassava into microbial protein on a large scale has been investigated only rather extensively in the last two decades.

The cassava project entitled Microbiological Enrichment initiated at the University of Malaya in 1973, sponsored by IDRC, has successfully produced a fermented cassava containing 10% true or digestible protein. Nutritional and safety evaluation trials on poultry and pigs have been undertaken and the preliminary results have been encouraging (Hutagalung and Tan 1977; Varghese et al. 1977). A similar cassava-enrichment project at the University of Guelph, also sponsored by IDRC since 1972, has revealed a process for producing microbial protein from cassava in a high-temperature low pH fermentation. High protein value biomass (36.9% protein) was obtained and the nutritive value of the product has been evaluated in rats (Reade and Gregory 1975; Gregory et al. 1976; Khor et al. 1976) and is being assessed in pigs. It is hoped that from these two cassava-enrichment projects, a product high in protein, in terms of quantity and quality, and nutritionally safe will be available on a larger scale to cope with the protein shortage for animal feeds.

Conclusions

The following conclusions can be drawn on the role of feed additives in cassava-based diets:

(1) Supplementation with feed additives is necessary to nutritionally balance the cassava-based diet and to improve its feeding value. These may include: (*a*) incorporation of fats or oils to improve palatability and to overcome the powdery characteristic, loose texture, and voluminous nature of cassava products and to facilitate nutrient absorption and retention in

the digestive tract; (*b*) supplementation with good quality protein feedstuffs or synthetic amino acids to balance protein and amino acids; (*c*) supplementation of nonprotein nitrogen to cassava-based diets, which appears more promising for ruminants than for nonruminants; (*d*) taking care to maintain the mineral balance of cassava-based diets, especially excesses of calcium, phosphorus, and oxalic acid, which can reduce the availability of zinc, copper, and iodine; (*e*) adjustments for certain vitamins (vitamin B_{12}, niacin, riboflavin, and biotin) that appear to be relevant in the cassava-based diet; (*f*) enrichment of cassava-based diets with natural or synthetic xanthophylls as required for pigmentation of skin, shanks, fats, and egg yolks of broilers and layers; (*g*) addition of antibiotics, fungicids, and antioxidants to cassava-based diets, which appears necessary to prevent contamination by microorganisms, rancidity, and deterioration of nutrients; (*h*) paying particular attention to standard specifications of cassava products, particularly their moisture, ash, and crude fibre contents, as these factors markedly reduce the nutritive value of cassava; (*i*) replacement of conventional feedstuffs (cereals) by cassava, which is economically feasible when the cost of the fortified cassava-based diet is lower than that of the conventional diet.

(2) Enrichment through microbial fermentation to increase the protein value of cassava has shown promising results, but the safety and economics of the microbially enriched cassava products should be of primary consideration prior to its use as animal feed.

Suggestions for Further Studies

The following points appear worthy of consideration:

(1) There seem to be great inconsistencies in the data on chemical composition of cassava products, particularly the "true protein" (nonextractable nitrogen) content, apart from the amino acid composition. Hence, there is a need to develop a simple and rapid procedure for the determination in the cassava products of the protein that is biologically available to animals, applicable for simple laboratory facilities in the developing countries. Consequently, a compilation of the data on chemical constituents of various cassava products should be undertaken.

(2) Apart from the cyanogenic glucosides of cassava, the possibility of enzyme-inhibiting factors in cassava should be investigated.

(3) Although in the previous workshop on chronic cassava toxicity (Zitnak 1973) the urgent need to develop simplified and reproducible analytical procedures for hydrocyanic acid (cyanogenic glucosides) has been stressed, such procedures are not yet available. These are of paramount importance so that investigators (nutritionists) can rapidly and accurately determine the cyanogenic glucosides content of cassava products prior to their use as animal feeds.

(4) The long-term effect of continuous feeding of cassava products on the whole life cycle of animals should be studied in depth.

(5) A study of the combined effects of cassava leaves and roots with various supplemented feed additives, to obtain their optimum combination in the diet as sources of protein and energy, should be initiated.

(6) Based on the suggestive evidence that ruminants have a greater tolerance to hydrocyanic acid than nonruminants, it appears necessary to undertake a basic study on the effect of feeding cassava products containing high concentrations of HCN on the metabolism of cyanides in the rumen and to compare the detoxifying ability of the ruminants with that of nonruminants.

Physiological and Biochemical Responses of Rats Given Potassium Cyanide or Linamarin

D. C. Hill[1]

Young rats fed, ad libitum, a diet containing 2400 ppm KCN showed no obvious signs of distress other than a decrease in weight gain. Similarly, rats fed for 12 weeks a diet deficient in vitamin B_{12} and methionine, and containing 1500 ppm KCN, appeared healthy, although weight gains were reduced by the deficiencies of B_{12} and methionine and by the addition of KCN. No evidence was found that the feeding of the KCN resulted in lesions in the central nervous system, spinal cord, or other tissues.

Linamarin administered by stomach tube in the absence of linamarase was partially metabolized to yield thiocyanate and a portion was absorbed intact from the gastrointestinal tract and excreted as such in the urine. Doses of 50 mg linamarin per 100 g body weight were invariably fatal, and some mortality resulted from doses of 25 mg, particularly if inadequate levels of methionine were provided. Rats receiving fatal doses of linamarin showed characteristic alterations in electrocardiograms similar to those resulting from fatal doses of KCN. Alterations in several biochemical parameters measured in the blood and in heart tissue were observed in these rats and also in rats receiving lesser but nonlethal doses. The toxicity of linamarin is mainly, if not entirely, due to cyanide released by the glucoside, and methionine contributes sulfur to aid in detoxification leading to thiocyanate formation.

The severity of the reaction to KCN and linamarin was strongly influenced by the manner in which they were administered. Mixed with the diet and fed over a period of hours they were tolerated in large amounts; whereas, death resulted from single large doses.

The cyanogenic glucoside, linamarin, occurring in cassava, flax, and lima beans is of great interest because of the widespread consumption of cassava by man and livestock.

Linamarin is the glucoside of acetone cyanhydrin. It is readily hydrolyzed by a heat labile β-glucosidase, linamarase, to yield acetone cyanhydrin, which can be split by a hydroxynitrile lyase, or nonenzymatically, into acetone and hydrogen cyanide (HCN). The enzyme complex is present in the plant tissue and is released when the cells are broken. Conn (1969) illustrated the pathway for the enzymatic degradation of linamarin.

It is generally believed that the toxic properties associated with linamarin and other cyanogenic glucosides are due to the HCN released from the glucoside by the activity of the enzyme complex. However, the incidence of acute poisoning from the consumption of cassava is relatively rare, a circumstance that no doubt is attributable to the processing procedures to which the roots are customarily subjected before consumption. Soaking, heating, and various extraction procedures are commonly used that inactivate the enzymes present and remove any free HCN that may have accumulated in the plant. Moreover, although HCN is a very toxic substance, significant amounts of ingested cyanide can be detoxified in the body.

Several routes of detoxification have been proposed, conversion to thiocyanate ion (SCN^-), incorporation into the 1 carbon metabolic pool through interaction with vitamin B_{12}, and conversion to 2-imino-4-thiazolidine carboxylic acid.

Lang (1933) postulated an enzyme rhodanese in liver and kidney that catalyzes the reaction of thiosulfate with HCN to give SCN^-, a relatively less toxic substance, which can be rapidly excreted. The properties of this enzyme, now known as thiosulfate sulfur transferase, and of a second enzyme, mercaptopyruvate sulfur transferase, also capable of forming SCN^- by sulfur transfer to cyanide have been reviewed by Sorbo (1975).

The possible involvement of vitamin B_{12} in cyanide detoxification was suggested by Wokes and Picard (1955). In this pathway, vitamin B_{12}, in the form of hydroxocobalamin (B_{12a}), reacts with cyanide to form cyanocobalamin (B_{12}). The latter then loses some of the cyanide to form 1-carbon fragments for the synthesis of methyl groups and the resultant hydroxocobalamin returns to the liver to repeat the cycle. Alternatively, the hydroxocobalamin can combine with the SCN^- formed via thiosulfate or mercaptopyruvic acid and proceed

[1]Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Canada.

to the formation of cyanocobalamin. Oke (1973) has outlined a scheme of detoxification of cyanide incorporating the joint intervention of thiosulfate, β-mercaptopyruvic acid, and vitamin B_{12}.

Wood and Cooley (1956) suggested a detoxification pathway in which cystine reacts with cyanide to give cyteine and β-thiocyanoalanine, the latter tautomerizing to give 2-imino-4-thiazolidine carboxylic acid, an inert compound that is excreted in the urine. There is no evidence to support other than a minor role for this reaction in the detoxification process.

Although it is by no means certain that the potential toxicity of linamarin resides only in its ability to release cyanide under appropriate conditions, a study of the response to cyanide ingestion is pertinent to an investigation of the metabolism of cyanogenic glucosides, including linamarin. The extreme toxicity of cyanide to most species is well known. The lethal dose for humans of potassium cyanide (KCN) taken by mouth is estimated to be between 1.0 and 7.0 mg/kg body weight and will cause death in a few minutes (Montgomery 1969).

Acute toxicity and death from the consumption of cassava is not a common occurrence; however, many workers believe that there may be chronic effects from the consumption of sublethal amounts of cyanide continually over a long period. The occurrence of human ataxic neuropathy and also goitre in Nigeria is greatest among those living in areas where cassava consumption is particularly high. The suggestion has been made that the neuropathy is caused or aggravated by cyanide or a derivative acting on the central nervous system and the thyroids enlarged by SCN^-, which is a well recognized goitrogen derived from the metabolism of the ingested cyanide. The subject has been extensively reviewed by Osuntokun (1973) and Wilson (1973).

Some support for the theory has been obtained from animal experiments. Smith et al. (1963) reported lesions in the central nervous system of rats injected repeatedly with sublethal amounts of KCN over a period of 22 weeks, with some suggestion of demyelination. In a later experiment (Smith and Duckett 1965), rats were injected daily for 5 weeks with KCN and a degeneration of neurons in the cortex and a degeneration of the corpus callosum were observed. However, only a small proportion of the injected rats showed these changes. Demyelination of the optic nerves and retina has been observed in rats given sublethal doses of cyanide over a period of 3 weeks (Lessel 1971), and cyanide poisoning has produced changes in the optic nerve of primates (Hurst 1940).

Little is known of the fate or possible toxicity of pure linamarin administered to animals in the absence of active linamarase or other substances that may accompany linamarin in its native plant source. Auld (1912) reported that guinea pigs fed up to 150 mg of linamarin over a 24 h period showed no obvious signs of a toxic reaction and concluded that linamarin itself was without effect when ingested. Winkler (1958) suggested that, under some conditions, microflora in the digestive tract may break down the glucoside and release HCN.

The experiments, whose descriptions make up the remainder of this review, fall into 2 groups, those in which KCN was administered directly to the rats, and those in which pure linamarin (purchased from Calbiochem Co. Inc., La Jolla, California) was used and the reaction of rats to its ingestion was investigated.

Response to Different Levels of KCN

This was a preliminary study to assess the toxicity for rats of dietary levels of KCN varying from 600 to 2400 ppm. The diet used in this experiment and most of the succeeding experiments was based on 10% of vitamin-free casein as the protein source, sucrose as the chief energy source, and premixes giving a complete complement of vitamins and minerals. A supplement of 0.3% DL-methionine was added, which, if omitted, rendered the diet deficient in methionine as reflected by reduced weight gains. In subsequent experiments it will be referred to as the "casein diet."

Results of the experiment were in good agreement with similar data reported by Maner and Gomez (1973). Increasing levels of SCN^- in the urine (0.02–11.3 mg/100 g feed eaten), and to some extent in the plasma (0.33–0.82 mg/100 ml), as KCN in the diet was increased from 0 to 2400 ppm showed that the rats were actively detoxifying the cyanide. While weight gains and feed consumption decreased as the level of KCN was increased in the diets all rats appeared healthy, even those receiving the diet containing 2400 ppm KCN. It can be calculated that rats receiving this diet consumed on the average 4.5 mg of KCN per day over

Table 1. Effect of KCN addition to diets deficient in vitamin B_{12} and methionine on weight gain (g), feed consumption (g), urinary SCN^- (mg/100 g food eaten), plasma SCN^- (mg/100 ml), thyroid weight (mg/100 g body weight), and liver weight (g/100 g body weight) of rats.[1,2]

	Avg. wt. gain		Avg. feed consumption		Urinary SCN^-		Plasma SCN^-		Avg. thyroid wt.[3]		Avg. liver wt.[3]	
	−	+	−	+	−	+	−	+	−	+	−	+
Complete	348	190	1496	1240	0.5	29.0	0.5	0.7	2.7	3.4	4.0	3.2
B_{12} deficient	324	157	1408	1032	—	19.1	0.4	0.7	2.7	3.0	4.1	4.2
Methionine deficient	245	57	1240	960	—	14.2	0.5	0.6	2.8	5.4	4.0	5.1
B_{12} and methionine deficient	197	58	1360	1360	—	19.3	0.4	0.6	1.7	5.8	4.2	5.3

[1]Each group consisted of 10 male rats fed the diets for 12 weeks from weaning. No mortality occurred during the course of the experiment. Values are those obtained at the end of the experiment.
[2]− indicates no KCN added to the diet; + indicates 1500 ppm KCN added.
[3]Interaction between the effects of methionine and KCN was significant for both thyroid and liver weights.

the 8 weeks of the experiment. In a later experiment, a single dose of 0.6 mg of KCN given by stomach tube to a 100 g rat was fatal in 30 min.

At the conclusion of the 8 week experiment period the rats were dissected for histological study. Examination of sections of the central nervous system stained with hemotoxylin and eosin, including observations on myelin and axons, and sections of the thyroid using periodic acid and leucofuchsin, revealed no differences among the 5 groups of rats that could be attributed to the diets.

Methionine and Vitamin B_{12} Deficiency and Ingestion of KCN

Because sulfur amino acids and vitamin B_{12} are believed to participate in the conversion of cyanide to SCN^- an experiment was designed to examine the influence of a dietary deficiency of these nutrients or the response of the rat to cyanide ingestion.

Groups of rats were fed the casein diet complete and modified by omitting separately and together the supplemental methionine and vitamin B_{12}. Diets were fed with and without 1500 ppm of added KCN.

Weight gains were significantly lower when supplemental methionine was omitted from the diet both in the absence and presence of KCN and when vitamin B_{12} was omitted in the absence of KCN. A high level of urinary SCN^- was associated with all diets containing KCN, with no clear evidence that the level was affected by methionine or vitamin B_{12} (Table 1).

The only statistically significant interaction in the experiment was that between the effects of KCN and vitamin B_{12} on weight gains. Vitamin B_{12} omission from the diet had a greater effect on weight gains in the absence of KCN than in its presence. If vitamin B_{12} has a function in the detoxification of cyanide one might expect the opposite, i.e. an increase in the apparent toxicity of cyanide with the deficiency of vitamin B_{12}.

The ingestion of KCN increased thyroid weights regardless of the diet composition, although the greatest effect was when the diet was deficient in methionine. This significant interaction between KCN and methionine in their effect on thyroid weights was also found for liver weights (Table 1).

Histological examination of tissue from the brain, pituitary gland, and spinal cord of representative rats from the various diets did not reveal any significant differences that could be attributed to the dietary treatments.

Response to Cyanide Ingestion

There is widespread belief that the rat, in comparison to many other species of animals, including man, has an exceptional ability to tolerate a high intake of cyanide. There can be no doubt, on the basis of the experimental results already reported, that the rat has a great capacity to detoxify cyanide, suggesting the possibility that a species more sensitive to cyanide would be preferable for cyanide studies. In the present experiment, the responses of guinea pigs, hamsters, mice, and rats to ad libitum consumption of a diet containing 1500 ppm KCN were compared. The diet used, guinea pig chow (Ralston Purina

Table 2. Weight gain (g), feed consumption (g), urinary SCN^- (mg/100 g feed consumed), and plasma SCN^- (mg/100 ml) of four species fed a diet with and without 1500 ppm KCN.[1,2]

	−KCN weight gain	−KCN food eaten	+KCN weight gain	+KCN food eaten	Urinary SCN^-		Plasma SCN^-	
					−KCN	+KCN	−KCN	+KCN
Rat	225 (9)[3]	1128	171 (9)[3]	1032	0.5^w	25.9^y	0.2^{wy}	0.4^{xz}
Guinea pig	374 (9)	2020	350 (7)	1880	0.5^w	21.6^y	0.3^w	0.5^x
Hamster	78 (10)	591	80 (8)	576	0.4^w	16.3^z	0.1^y	0.3^z
Mouse	19 (10)	395	15 (9)	379	0.1^x	14.9^z	0.2^w	0.6^x

[1]Diet in all cases was ground guinea pig chow (Ralston Purina Co.).

[2]For weight gain and feed consumption studies 20 weanling animals from each species were divided into two groups of 10 each of equal average weight at the start of the experiment. Diets were fed for 12 weeks. For urinary and plasma SCN^- each value is the average for seven rats.

[3]Number of surviving animals.

NOTE: Values with a common superscript are not statistically different ($p > 0.05$).

Co.), was a compromise to providing a separate diet formula for each species, and was believed to be nutritionally adequate for each of the species studied. Ten animals were fed the chow diet, with and without 1500 ppm KCN, for 12 weeks from weaning.

With the exception of the hamster, weight gains were depressed by the addition of cyanide (Table 2). Of the animals receiving cyanide, three guinea pigs, one rat, two hamsters, and one mouse died during the course of the experiment. Of the control animals one guinea pig and one rat died. Feed consumption was not drastically reduced by the addition of KCN to the diet, although the decreases were statistically significant in the case of the rat, guinea pig, and mouse.

For each species the addition of cyanide to the diet significantly increased both the urinary output of SCN^- and the plasma concentration of SCN^- (Table 2).

Histological examination of the brain tissue revealed no significant differences between the control and KCN fed animals for any of the four species. Some animals had vacuolation around cells in the white matter but this was observed in both control and treated groups.

No lesions were observed in any of the other tissues examined (thyroid gland, adrenal gland, spinal cord, and optic nerve).

Although it must be accepted that the rat has a great capacity to dispose of large amounts of ingested cyanide it does not appear to be unique in this respect among other commonly used experimental animals. Each species consumed the cyanide supplemented diet quite readily and, with the possible exception of the hamsters, which had no reduction in weight gain associated with KCN consumption, showed about the same response to cyanide ingestion.

Sources of Sulfur for Cyanide Detoxification

Although direct evidence is lacking, it is generally accepted that methionine, via cysteine, commonly serves as a sulfur donor for the formation of SCN^- from cyanide. A possible role of inorganic sulfate ($SO_4^=$) as a sulfur donor is not without interest. One would not expect $SO_4^=$ to participate in the formation of SCN^- because as far as it is known nonruminant animals cannot reduce hexavalent sulfur. On the other hand, there is evidence that sulfate sulfur given to chicks can be incorporated into the cystine of feathers (Machlin et al. 1954).

Barrett et al. (1977a) compared $SO_4^=$ and methionine as sources of sulfur for SCN^- formation by rats receiving KCN in their diet. The basal diet was the casein diet with the supplement of methionine omitted and the mineral portion modified to be free of $SO_4^=$. Their results supported a modest role for $SO_4^=$ in the synthesis of SCN^- (Table 3). Rats fed the basal diet alone barely gained in weight. This was not surprising; the limited amount of methionine present in the casein was called upon to supply: (1) $SO_4^=$ by oxidation of the amino acid sulfur to meet specific needs for this ion; (2) methionine itself for protein synthesis; and presumably (3) sulfur for the conversion of CN^- to SCN^-. The addition of methionine to the basal diet greatly increased weight gain and also increased urinary and plasma SCN^-. Although less effective than methionine, the addition of K_2SO_4 also increased weight gains and clearly had some effect on the conversion of CN^- to $SCN^=$. The

Table 3. Effect of methionine and sulfate on weight gains (g) and urinary SCN^- (mg/100 g food eaten) and plasma SCN^- (mg/100 ml) levels of rats receiving KCN.[1]

	Avg. wt. gain	Urinary SCN^-	Plasma SCN^-
(1) Basal (low methionine, SO_4 free)	1.6	8.8^w	0.5^w
(2) +0.4% DL-methionine	44.6	34.2^x	1.8^y
(3) +0.46% K_2SO_4	13.2	16.1^w	0.7^w
(4) +0.2% DL-methionine + 0.23% K_2SO_4	32.9	26.9^x	1.4^x

[1]Values are averages for 5 male rats for diet 1 and 12 rats each for diets 2, 3, and 4. Rats were fed from weaning for a period of 3 weeks. All diets contained 1500 ppm KCN.

[wxy]Values with a common superscript are not significantly different ($p > 0.05$).

effect of K_2SO_4 supplementation could be attributed to its satisfaction of specific needs for $SO_4^=$, thus sparing the methionine in the basal diet that would otherwise be required for this purpose.

To confirm a role for methionine and possibly a direct role for $SO_4^=$ in the conversion of cyanide to SCN^-, ^{35}S methionine and ^{35}S Na_2SO_4 were injected into rats receiving diets 2, 3, and 4 of Table 3 following a 16 h fast. Diets were immediately replaced after injection and the urine collected for the following 24 h. The SCN^- was separated from other metabolites in the urine by paper chromatography and the ^{35}S in the SCN^- fraction measured by liquid scintillation counting.

It is evident (Table 4) that both methionine and Na_2SO_4 contributed sulfur to the formation of SCN^-. The percent recovery of the injected ^{35}S in the case of methionine supplementation was much less than was the case for sulfate, but this would be expected as relatively large amounts of methionine are metabolized in the body as compared with sulfate. The relative activity of the two sulfur sources as sulfur donors was approximately in proportion to the urinary SCN^- recorded in Table 3, although it is not clear why the rats that received the combination of methionine and K_2SO_4 in the diet contributed more ^{35}S to $SCN^=$ than those fed the diet supplemented with K_2SO_4 alone. The difference between the two values was not statistically significant.

Effect of Linamarin on Thiocyanate Levels and Thyroid Uptake of ^{131}I

In a first experiment with linamarin, a large amount of the glucoside was fed to rats and evidence sought for its metabolism through changes in SCN^- levels and thyroid uptake of ^{131}I.

Weanling male rats were fed the casein diet and the diet unsupplemented with methionine for 2 weeks. On each of the last 3 days of this period, half of the rats were allotted 10 g of feed, and the other half, 10 g into which 80 mg of linamarin had been mixed. Urine was collected from each rat for 24 h before feeding linamarin and daily during the 3 days of linamarin feeding. On the morning of the 4th day each rat was injected with Na ^{131}I and killed 6 h later. Blood samples were drawn from the heart before death, and the thyroids were removed and their radioactivity measured in an automatic gamma counting system.

Regardless of the presence or absence of supplemental methionine the ingestion of linamarin resulted in a small but statistically significant increase in plasma and urinary SCN^- and a decrease in ^{131}I uptake by the

Table 4. Incorporation of ^{35}S from labelled methionine and sulfate into urinary thiocyanate[1]

	Compound injected	^{35}S recovered in urine (% injected dose)	^{35}S as SCN^- in urine (% injected dose)	^{35}S as SCN^- (% total ^{35}S in urine)
0.4% DL-methionine (2)	L-methionine ^{35}S	18.7^w	5.0^w	27.8^w
0.46% K_2SO_4 (3)	$Na_2{}^{35}SO_4$	57.9^x	2.9^x	5.2^x
0.2% DL-methionine + 0.23% K_2SO_4 (4)	$Na_2{}^{35}SO_4$	41.7^y	4.4^{wx}	10.5^x

[1]Each value is the mean for 6 rats.

[2]Diet fed up to 16 h before and following injection of the radioactive compound. Numbers in parentheses refer to diet number given in Table 3.

[wxy]Values with a common superscript are not significantly different ($p > 0.05$).

thyroid. A reduction of ^{131}I uptake by the rat thyroid in short-term experiments has been attributed to the goitrogenic activity of SCN^- (Delange et al. 1973).

The consistent evidence for increased SCN^- formation when linamarin was administered provided definite evidence that at least a portion of the linamarin had been metabolized.

Linamarin Given by Stomach Tube

In this study (Barrett et al. 1977b) male rats were fed the casein diet from weaning. When their weights were approximately 100 g they were individually dosed by stomach tube with linamarin dissolved in water. Following dosing, feces, urine, and blood were analyzed for linamarin (Zitnak et al. 1977) and the blood for SCN^-.

In a preliminary experiment, 10 rats received a dose of 50 mg of linamarin and seven died within 4 h. Six rats, dosed with water only, showed no abnormal reaction. Just before death electrocardiogram tracings were recorded for two rats. Abnormal patterns were obtained that were similar to those reported for humans who had consumed a lethal dose of cyanide (Wexler et al. 1947).

Because of the lethal effect of 50 mg, the dose was reduced to 30 mg and at this level all rats survived.

No linamarin was detected in the feces or blood of these rats. However, 5.65 mg of linamarin was found in the urine along with 0.743 mg of SCN^- (0.65, 0.07, and 0.023 mg, 24, 48, and 72 h after dosing, respectively).

Failure to find linamarin in the feces means that within the limits of the analytical method the administered linamarin was either absorbed completely intact or partially hydrolyzed and the products absorbed and/or lost in the feces. Failure to find linamarin in the blood, even though it appeared in the urine, could reflect a quite dilute level of linamarin in the blood, which was concentrated by the kidney. It is also possible that linamarin may be bound to blood proteins in a form not recovered by the methanol extraction step used in the analysis.

The 0.743 mg of SCN^- excreted above the base level in the urine over a period of 3 days theoretically could have been formed from 3.16 mg of linamarin. Of the 30 mg of linamarin given the rats, therefore, 8.81 mg (3.16 + 5.65) was accounted for.

Changes Associated with Linamarin Administration

An oral dose of 50 mg of linamarin given to rats weighing about 100 g resulted in death of the animals within a few hours. It is reasonable to attribute this severe ration to a large amount of cyanide released from the linamarin following its ingestion.

An experiment in which rats were given either a lethal dose of linamarin (50 mg/100 g BW) or of KCN (0.6 mg/100 g BW) by stomach tube revealed close similarities in response to the two cyanide compounds. Both produced ataxis, apnea, docility, and paresis, although only the KCN dosed rats developed a severe cyanosis. All linamarin dosed rats died in about 4 h and KCN dosed rats in about 30 min.

Because cyanide is known to affect heart function in a characteristic manner (Woolman and Dripps 1970) electrocardiograms from linamarin and KCN dosed rats were compared. There were many similarities in the tracings given by the rats receiving the two compounds, including cardiac arrhythmias, changes in the electrical stimulation of the heart, and a decreased heart rate (Fig. 1).

Quantitative evaluation of certain of the changes in cardiac function are given in Table 5 and of some biochemical measurements in Table 6. Compared with control values whole blood lactic acid was elevated in rats dosed with linamarin or KCN, whereas pyruvic acid was essentially unchanged. The increased lactate/pyruvate ratio is indicative of severe cardiorespiratory failure. This phenomenon has been attributed to an increased activity of lactic acid dehydrogenase acting in a reverse capacity (Broder and Weil 1964).

Decreased cytochrome oxidase activity also observed is a well recognized result of cyanide poisoning and has been cited as a cause of the arrhythmias seen after cyanide administration (Ballantyne et al. 1972; Schubert and Brill 1968).

In the above studies the diet used was Purina Rat Chow fed ad libitum. This diet was carefully checked for any ability to release HCN from linamarin by incubating a portion of the diet along with linamarin, with and without an active linamarase concentrate prepared from flax seedlings. Only when the active linamarase preparation was included in the incubation mixture was there a detectable production of HCN.

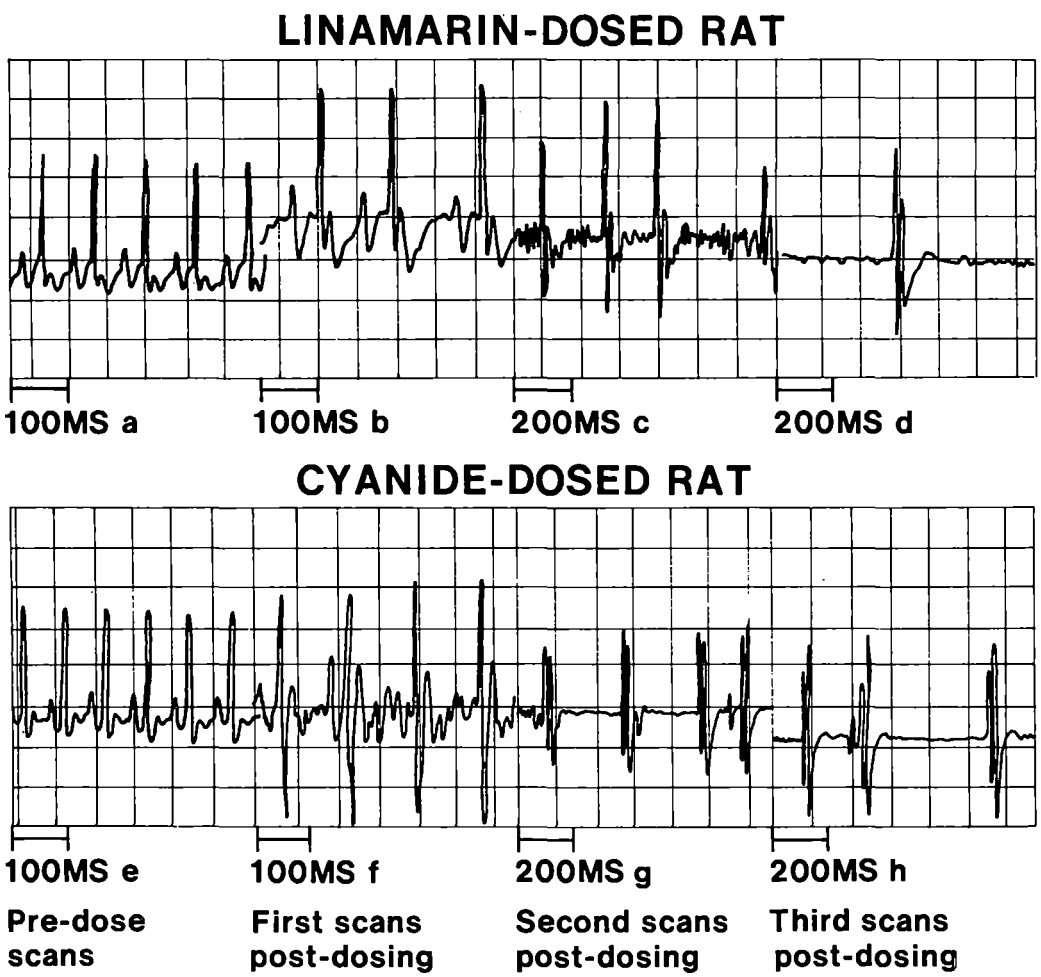


Fig. 1. Effects of linamarin and cyanide dosing on cardiac rhythm. All traces were obtained in Lead II at an amplitude setting of 0.5 V/D. Traces a and e were taken 24 h before dosing, traces b–d were taken 3 h 58 min to 4 h 13 min after dosing, and traces f–h were taken 11–25 min after dosing.

Table 5. Effects of linamarin (50 mg/100 g BW) and KCN (0.6 mg/100g BW) given orally on certain cardiac functions of the rat.

	Linamarin[1]			KCN[1]		
	Predose	1st scan	2nd scan[1]	Predose	1st scan	2nd scan[1]
Heart rate (beats/min)	471 ± 3[2]	317 ± 20*	243 ± 14*	479 ± 5	300 ± 22*	241 ± 23*
Mean electrical axis[3]	+70 ± 8	+114 ± 17*	+135 ± 22*	+79 ± 3	+128 ± 14*	+85 ± 15*
Respiration rate (breaths/min)	87 ± 10	27 ± 5*	26 ± 7*	88 ± 6	97 ± 11	40 ± 12*
Minute volume[4] (ml/min)	72 ± 10	8 ± 4*	9 ± 5*	82 ± 11	56 ± 13	18 ± 10*

[1]Predose values were obtained 24 h before dosing. Average times from dosing for 1st and 2nd scans were for linamarin 3 h 58 min, 4 h 13 min and for KCN 14 min, 25 min.
[2]Mean ± S.E.M. for a minimum of 6 rats per group.
[3]Changes in mean electrical axes are indicative of an altered electrical stimulation of the heart.
[4]Amount of air taken in per min in breathing.
*Significantly different from predose value according to Student's "t" test ($p < 0.05$).

Table 6. Effects of linamarin (50 mg/100 g BW) and KCN (0.6 mg/100 g BW) given orally on certain biochemical measurements in the rat.

	Control (4)[1] (distilled H_2O)	Linamarin (6)	KCN (5)
Blood lactic acid (mg/100 ml)	23±3[2]	64±4*	43±6*
Blood pyruvic acid (mg/100 ml)	1.5±0.2	1.4±0.2	1.3±0.1
Lactate/pyruvate	15±1	43±4	34±2
Cardiac cytochrome oxidase activity (m μM substrate oxidized/10 min/μg protein)	2.8±0.4	0.8±0.2*	0.7±0.5*

[1]Number in parentheses is number of rats per group.
[2]Mean ± S.E.M.
*Significantly different from control group according to Student's "t" test ($p < 0.05$).

The previous investigation was extended to include other biochemical measurements. The dosing technique was the same but in addition to the 50 mg/100 g BW dosing of linamarin, known to be lethal, a 25 mg dose was used. The casein diet was fed to the rats both with and without supplemental methionine. As before, rats receiving the 50 mg dose died in about 4 h. There was no apparent influence of the presence or absence of supplemental methionine on the outcome. Electrocardiogram tracings recorded before death of the rats were comparable to those obtained in the previous study following the administration of either linamarin or KCN.

Surprisingly the 25 mg dose produced clinical signs of toxicity including apnea, ataxia, and paresis. These signs were particularly evident when the diet was deficient in methionine, in which case about 50% of the rats died in approximately 4 h. Abnormal electrocardiogram tracings were also observed following the 25 mg dose. Even with adequate methionine in the diet 10% of the rats receiving 25 mg of linamarin died and about 40% showed no toxic signs. Both dose levels decreased cardiac cytochrome oxidase activity and increased blood lactic acid levels, although the increase in the latter was less in the case of the 25 mg dose.

Additional biochemical data from the analysis of heart tissue and blood are given in Table 7. The partial pressures for CO_2 and O_2 in the blood and the bicarbonate ion level were significantly altered in most cases by linamarin dosing, indicative of metabolic acedosis and an alteration in the buffer capacity of the blood. In general, ATPase activities were significantly reduced by linamarin, symptomatic of an interference with the release of energy in the heart tissue. Na^+K^+ dependent ATPase was affected by the 25 mg dose but not by the 50 mg. Possibly the more rapid development of toxicity with the latter dose level prevented an effect on this enzyme that was evident at the lower dose. It is of considerable interest that the activity of this enzyme in the heart is specifically reduced by the glucoside, digitalis, raising the possibility that linamarin may exert a toxic effect partly by a mechanism independent of HCN.

Prolonged Daily Dosing with Linamarin

Four groups of five male rats were fed ad libitum from weaning for 5 weeks. Two groups received the casein diet and two groups the casein diet without supplemental methionine. Two groups, one from each dietary treatment, received daily by stomach tube a dose of 9.4 mg linamarin/100 g BW. This dose level was calculated to have the potential of providing 0.25 mg of cyanide/100 g BW/day, approximately the minimum lethal dose for rats when administered intravenously (Stecker 1968). Control rats received an equivalent amount of water by stomach tube.

Weight gains were recorded and several biochemical measurements were made at the end of the 5-week experimental period (Table 8).

Weight gains were not significantly altered by the treatment with linamarin and there was no mortality. However, the lactate/pyruvate ratio was significantly increased by linamarin dosing and cardiac cytochrome oxidase activity significantly decreased. Their alterations, as noted before, are indicative of

Table 7. Effect of linamarin dosing of rats on blood and heart measurements.[1]

Group[3]	Blood measurements[2]						Heart ATPase (M phos. hydrolyzed/10 min/mg protein)[2]		
	pCO_2		pO_2		HCO_3				
	BD[4]	AD	BD	AD	BD	AD	Total	Na^+K^+ dependent	Mg^{++} dependent
(1) Methionine deficient							37 ± 7 (4)	9 ± 2	3 ± 0.3
(2) Methionine adequate							25 ± 3 (4)	11 ± 2	5 ± 0.6
(3) (1) + 50 mg linamarin	57 ± 3 (8)[5]	34 ± 3*	45 ± 3	87 ± 13*	29 ± 1	15 ± 4*	38 ± 4 (4)	8 ± 2	1 ± 0.2*
(4) (2) + 50 mg linamarin	64 ± 6 (6)	34 ± 5*	44 ± 8	65 ± 8*	29 ± 1	15 ± 4*	15 ± 3* (4)	11 ± 1	1 ± 0.1*
(5) (1) + 25 mg linamarin	69 ± 1 (10)	37 ± 4*	45 ± 3	58 ± 8*	28 ± 1	19 ± 3*	8 ± 3* (4)	5 ± 1*	2 ± 0.3*
(6) (2) + 25 mg linamarin	60 ± 3 (7)	37 ± 6*	48 ± 4	51 ± 15	29 ± 1	25 ± 6	8 ± 1* (4)	5 ± 1*	2 ± 0.3*

[1] All animals killed by decapitation, 3.5 h after dosing with H_2O or 4.5 h after dosing with linamarin.
[2] Values are means ± S.E.M.
[3] Dose levels are per 100 g BW.
[4] BD = before dosing; AD = after dosing.
[5] Number of rats in group in parentheses.
* Significantly different from corresponding control value by Student's "t" test ($p < 0.05$).

metabolic disturbances related to linamarin ingestion. The significant increase in urinary SCN^- for rats receiving linamarin is most likely a reflection of an active detoxification of HCN arising from the glucoside.

Conclusions

Since the critical studies presented here were done with rats, interpretation of the findings must be confined to this species.

Rats appear to have a great capacity to tolerate a continuous intake of cyanide at quite a high level, e.g. a diet containing 2400 ppm KCN, without obvious signs of distress, other than a reduction in weight gains. However, there was no evidence that the rat differed from the guinea pig, hamster, or mouse in this respect.

Although the possibility of pathological lesions in the central nervous system, spinal cord, and other organs arising from long term ingestion of cyanide cannot be ruled out, no evidence for such a relationship was found in these investigations. Some rats were fed for as long as 12 weeks with a diet containing 1500 ppm KCN and deficient in methionine and vitamin B_{12}.

Pure linamarin, in the absence of linamarase, was partially metabolized to yield SCN^- following ingestion, although a portion was absorbed intact and excreted as such in the urine. It appeared that the toxicity of linamarin to the rat depended greatly on the manner in which it was administered. Fed as a mixture with food, it appeared to be well tolerated even in large amounts. However, given as a single dose by stomach tube a large dose was lethal, and a smaller dose continuously administered produced biochemical effects.

The results strongly suggest that the toxicity of pure linamarin resulted mainly, if not entirely, from the cyanide released during its metabolism. The variable severity of the effects observed with different modes of administration was probably a reflection of the rate and absolute amount of cyanide released into the system, and whether or not the channels of elimination could adequately cope with the cyanide.

Results confirm the generally accepted belief that the level of dietary sulfur amino acids is an important factor in influencing the toxicity of cyanide, and can contribute sulfur

Table 8. Response of rats to daily dosing with linamarin for 5 weeks from weaning.[1,2]

	Dietary treatment				
	Methionine adequate	Methionine deficient	Methionine adequate + linamarin	Methionine deficient + linamarin	Significant effects
Avg. wt. gain (g)	161±17	104±7	160±8	91±5	methionine
Systolic blood pressure (mm Hg)	107.2±3.9	98.3±4.4	87.4±5.9	86.9±2.7	methionine × linamarin
Blood lactate/pyruvate ratio	10.3±1.2	13.5±1.1	20.3±1.5	28.7±4.6	linamarin
Cardiac cytochrome oxidase activity (m μM substrate oxidized/10 min/μg substrate)	2.4±0.1	2.4±0.1	1.1±0.2	0.9±0.2	linamarin
Urinary SCN^- (μg/100 BW/24 h)	0.5±0.0	0.7±0.1	1.9±0.3	2.2±0.5	linamarin

[1]Values are averages for 5 male rats.
[2]Rats received daily by stomach tube 9.4 mg linamarin per 100 g body weight.

for the formation of SCN^- from cyanide. It was shown that the sulfur from sulfate ion can also contribute to the synthesis of SCN^-.

The author is grateful to the following by whose efforts the data of this report were obtained: J. C. Alexander, Mearle D. Barrett, Diana J. Philbrick, all of the Department of Nutrition; A. Zitnak, Department of Horticultural Science and R. G. Thomson and G. Losos, Department of Pathology.

Cassava in the Nutrition of Broilers

J. J. Montilla[1]

One of the main obstacles to efficient animal production in the tropics is the lack of excess agricultural products that can be used as raw materials for animal rations. Cassava products (roots and foliage) appear to be one of the best possibilities for overcoming the chronic deficit in tropical agricultural production. The majority of the research carried out during the last 10 years shows that cassava root flour can be substituted for cereals in broiler rations at levels of up to 30%. When the diets are prepared in the form of pellets it appears possible to use cassava root meal and cassava foliage meal at levels up to 50 and 20%, respectively. The author strongly believes that even if a deterioration of 10% occurs in body weight increase and feed efficiency, cassava-based diets can be an economically feasible proposition within the framework of the developing countries. It is proposed that broiler feeding experiments utilizing cassava products not only evaluate body weight increase and feed efficiency, but also state the product yield in terms of production per hectare as this is a more logical approach to an agricultural activity. In addition, several areas of research requiring emphasis are suggested.

Although man's interest in birds dates from the beginning of the first civilizations, their utilization as domestic animals destined for massive production of high value food for human consumption has been more recent. For example, the 9.3 million metric tonnes of eggs and 4.0 million tonnes of poultry meat produced in the world annually between 1948–52, rose to 22.3 million tonnes and 19.0 million tonnes, respectively, in 1972; an increase of 240 and 465% in only two decades (FAO 1973). This impressive increase permitted consumption of eggs and poultry meat to rise from 3.72 and 1.6 kg to 5.9 and 5.1 kg annually per capita, but it has not taken place evenly in all countries.

About 1663.5 million fowl in the developed countries of the western world produce 11.5 million tonnes of meat and 11.5 million tonnes of eggs. The less-developed countries, situated mainly in the tropical areas, produce only 2.3 and 3.3 million tonnes of meat and eggs respectively, in spite of their having 1780 million fowl; in the socialist countries 2340 million fowl produce 5.2 and 7.5 million tonnes of meat and eggs. The above data show the enormous difference in the human consumption of avian products (meat and eggs) that reaches, in terms of kilograms per person per year, 31.2 kg in the developed countries of the western world, only 3.1 kg in the tropical less-developed countries, and 7.3 kg in the socialist countries (FAO 1973).

The exceptional increase in poultry production achieved in the last few decades has been possible because of improvements in genetics, sanitation and hygiene, management, and nutrition. The goals achieved in these fields have been possible because of extensive investments of material and time. We can now say which countries can rely on good poultry genetic material, good sanitation and hygiene methods to control diseases and plagues, and good management systems, which give the birds adequate comfort for optimal production, without causing too great an investment on the part of the country concerned. Unfortunately the same is not true with animal nutrition. The development of avian production is one of the ways by which the western developed countries and the major part of the socialist bloc transform their agricultural excess into products more appetizing and of exceptional nutritional value. These excesses simply do not exist in a tropical area; on the contrary, there exists a deficiency with regard to direct human nutrition. For this reason, only countries like Venezuela (with an enormous income due to revenues from oil exportation, which allows exceptionally high importation of raw material for animal feeding) have developed avian production to provide an important contribution to human nutrition.

The principal plant harvests on a world basis are cereals (1275 million tonnes), of which the developed countries of the western world and the socialist bloc countries produce 452 and 457 million tonnes respectively, i.e. 35.5 and 35.8% of the total; the developing countries, with 47% of the human population, only produce 367.3 million tonnes (28.7%). The situation is graver still when one considers that in

[1]Departamento de Producción Animal, Facultad de Ciencias Veterinarias, Universidad Central de Venezuela, Maracay, Venezuela.

the developing countries 289.6 million ha are cultivated, which represents 41.5% of the world area utilized for this type of cultivation. The situation is very similar for roots and tubers, which occupy second place in relation to the volume of world production; the developing countries only produce 29.5% of the world total (166.2 million tonnes, of a total of 563.4 million tonnes).

The tropical developing countries only lead in the production of crops of lesser importance in relation to the total volume produced, such as grains, fruits, vegetable oils, sugar, coffee and cocoa, vegetable fibres, tobacco, and rubber. It must be considered that a significant part of the production is not devoted to internal consumption but is exported.

A much more serious problem is detected when the world production of animal food is analyzed. The developed countries of the western world, with 20% of the total human population, produce 48.8% of the meat, 49.4% of the milk, and 51.3% of the eggs. The socialist bloc countries, inhabited by 33% of the human population, produce 33%, 29.9%, and 33.5% respectively. The developing countries, with 47% of the population, produce only 18.3% of the meat, 19.9% of the milk, and 14.7% of the eggs.

In summary, of the 2751 million tonnes of plant products produced in the world, 827 million tonnes (30%) come from the developed countries, 840 million tonnes (30.5%) from the developing countries, and 1087 million tonnes (39.5%) from the socialist countries; of the 546.4 million tonnes of animal products for human consumption, 269.6 million tonnes (49.3%) are produced in the developed countries of the western world, 109.4 million tonnes (18.1%) in the developing countries, and 167.4 million tonnes (32.6%) in the socialist countries.

Cassava, until recently relegated to the area of scientific research, is without doubt one of the best possibilities for overcoming the chronic deficit in tropical agricultural production. This type of cultivation, without the technological expertise that is applied to the production of cereals, and with a minimal input, gives an average production of 10 000 kg/ha in the tropics, equivalent in energy value to 3500 kg of cereal. In countries such as Brazil, average production is already higher than 15 000 kg/ha. Harvests of more than 30 tonnes of roots per hectare are commonly obtained in Venezuela, and it is considered that this volume of production is a feasible goal when the cultivation of high-yielding varieties becomes more generalized, and when suitable methods of cultivation are applied (Montaldo 1973).

Without question, green plants represent the most abundant and economical source of protein because they synthesize amino acids through photosynthesis, which is based on primary products available in unlimited amounts: solar energy, carbon dioxide, water, and inorganic nitrogen (atmospheric in the case of legumes). The amino acids synthesized in this way are polymerized into a more stable form as proteins, and stored in the leaves. As the process takes place, principally during the early leaf stage, the tender green leaf material possesses the greatest protein value (Oke 1973). In this respect, cassava foliage cut at intervals of between 60 and 90 days constitutes an excellent possibility (Montilla 1976).

There exists sufficient evidence to demonstrate the feasibility of utilizing cassava root flour as an energy source, and cassava leaf flour as a supply of certain of the protein requirements in broiler feeds.

Cassava Root Flour

Cassava is one of the oldest crops in tropical America. The Indians learned how to process the root by drying it and converting it into a product which, in addition to increasing its useful life span, became harmless due to the elimination of hydrocyanic acid (HCN), which is especially abundant in the so-called "sour" varieties. Following the discovery of America, cassava was passed to the tropical areas of Africa and Asia where it soon became a basic food. However, it is only during the last few decades that interest has been shown in utilizing it in balanced feeds for animals.

In 1935, Tabayoyon in the Philippines, studied a product derived from the extraction of cassava starch, the chemical composition of which was: moisture 10.56%; protein 1.03%; fat 0.62%; crude fibre 4.76%; ash 1.22%; and carbohydrate 81.91%. This material was incorporated at 30 and 60% levels into mixes for chicken production, together with other ingredients such as rice bran, corn meal, and shrimp meal. Body weights at 12 weeks were 517.7, 463.4, and 388.0 g for birds that ate feeds containing 0, 30, and 60% of the cassava

by-product. The amount of feed consumed was 2.55, 2.28, and 2.24 kg. The results of this work are of great importance when one starts to think of cassava not only with regards to its direct use as food for man and domestic animals, but also its increased use for industrial processing.

Olson et al. (1969) determined the metabolizable energy (M.E.) of cassava root flour, prepared by peeling and grinding the root, compressing it to remove water, and drying in an oven at approximately 100 °C. These workers reported caloric values of 3.44 and 3.09 kcal/g of M.E. for the dry and the 10% moisture flour, respectively. In 1972 Maust et al. determined the M.E. of cassava root flour from Thailand classified as "suitable for human consumption." The flour contained 1.1% neutral detergent fibre, 0.0% acid detergent fibre, 0.1% crude protein, and 4306 kcal/kg of total energy. The M.E. value (dry base) was 4.31 kcal/g. Muller et al. (1974) reported M.E. values in Singapore of 3650 kcal/kg for cassava root flour and 3660 kcal/kg for yellow corn grain. Hutagalung et al. (1974) report an M.E. level of 3230 kcal/kg for cassava root flour. Such diverse energetic values are due to the use of different products. They may also reflect differences in chemical composition caused by age, time of harvest, and methods of processing (Barrios and Bressani 1967).

With respect to the digestibility of the cassava root flour fractions by poultry, Vogt (1966) reports crude protein 75%, crude fat 70%, crude fibre 55%, and nitrogen-free extract 99%.

McMillan and Dudley (1941) fed chickens diets containing 20 and 40% cassava root flour and did not notice deleterious effects on health; however, the higher level of substitution produced a reduction in weight gain.

Klein and Barlowen (1954) recommended using cassava root flour at levels of up to 10%, because higher levels were reported to decrease weight gain and feed efficiency. They affirmed that cassava flour contained a factor that diminished feed consumption. Wegner (1961) obtained satisfactory results by feeding broilers rations containing 8% cassava root flour.

Vogt and Penner (1963) incorporated up to 30% cassava root flour into broiler rations. Productivity was normal with 10%, but with 20 and 30%, weight gain and feed efficiency deteriorated. According to these workers the adverse effect occurs mainly in the first few weeks of life. Vogt (1966) affirmed that only after the fourth week can broilers consume cassava root flour at levels higher than 10%.

Yoshida et al. (1966) found that young birds grew well when fed with 10% cassava root, but that higher levels resulted in delayed growth. Moistening the cassava overnight or autoclaving it at 120 °C for 1 h significantly increased the rate of growth of the birds. The authors suggested that HCN, present in the flour (36 ppm), was responsible for the low level of growth.

Enriquez and Ross (1967) studied in 1-day-old Leghorn chicks the effect of incorporating up to 50% cassava root flour into a diet whose principal protein source was formed by fish meal, meat and bone meal, and soybean flour. The composition of the cassava flour was: moisture 11.78%; crude protein 1.73%; crude fat 0.50%; crude fibre 2.2%; ash 3.79%; and nitrogen-free extract 80.09%. The fresh material came from a sweet clone, and was obtained from plants 11–16 months old. The cassava was harvested, washed, cut, and dried for 24–48 h in a grain drier at 50 °C. The flour prepared in this way showed very low levels of HCN. At 3 weeks of age, deterioration in weight gain and feed efficiency was statistically significant when cassava flour levels in excess of 20% were used. The addition of molasses and soybean oil had no beneficial effect, which demonstrated, according to the authors, that the problem was not one of palatability or essential fatty acid deficiency. On the other hand, supplementation with 0.15% methionine corrected the adverse effects. The authors concluded that if the ration was balanced with respect to protein and methionine, cassava flour could satisfactorily replace all the corn in the diet. The response to methionine was probably due to the fact that by increasing the levels of cassava in the rations it was also necessary to increase the levels of soybean flour (in the protein of which methionine is the most limiting amino acid). Olson et al. (1968) affirmed that although cassava root flour contains 92% of the M.E. of corn, they only obtained a 72% weight increase and a deterioration of feed efficiency when compared with the cereal.

Soares et al. (1968) studied levels of partial and total substitution of corn with cassava root flour in 1-day-old New Hampshire chicks, and also substitution of the corn with approximately equal amounts of cassava root flour and

wheat flour. In the first instance the cassava flour reached a maximum incorporation of 34.30% in the ration, and in the second case the cassava plus wheat reached 20.16%. The best weight increases and feed efficiencies were obtained with 12 and 18% cassava flour, and with 6 and 12% of the mixture. Majarrez et al. (1973) combined cassava flour and rice polishings in the proportion 40:60, and called the mixture "cassavarice." These workers considered that the mixture could partially substitute grain in balanced diets. In 1-week-old broilers, they studied levels of 0, 50, and 100% "cassavarice" as a corn substitute, using exclusively isoprotein rations. No significant differences were encountered with reference to weight increase, but differences were detected in relation to feed efficiency ($p < 0.01$). The mean values were 2.41, 2.57, and 2.93, respectively, for the different levels used. They concluded that the use of "cassavarice" was possible, its use being dependent on the price of the raw materials.

Rendon et al. (1969) studied the incorporation of 0, 15, 30, and 45% cassava root flour in diets for broilers, and reported a decrease in weight gain and feed efficiency for all levels studied; however, with the 15% level the differences were lower. The authors confirmed the existence in cassava flour of a factor that reduced feed intake in birds receiving the highest levels. Gadelha et al. (1969), using 1-day-old broiler chicks, studied the effects of substituting cassava root flour for corn at levels of up to 45% in diets supplemented with 0.20% methionine. They observed a decrease in weight gain and feed efficiency at all levels studied; however, the lower cost of the cassava flour made the 15% diet more economical. The consumption of the food was not affected in these diets.

Olson et al. (1969) tested peeled cassava root flour in broiler rations, incorporating it in amounts from 7.5 to 45.0%, and making the rations isocaloric and isoproteinaceous by means of the addition of animal fat and soybean flour. They found that although the gain in weight was slightly reduced by increasing the incorporation of cassava flour, significant differences only appeared at the higher levels (37.5 and 45.0%); the feed efficiency response was similar. They concluded that peeled cassava root flour could be incorporated into diets for chicks at levels of up to 30% without affecting weight increase if the feed was balanced for energy and protein. Tejada and Brambila (1969) studied the incorporation of up to 50% (0, 12.5, 25, 37.5, and 50%) washed cassava root flour in diets for Leghorn chicks, in substitution of corn, and found no significant differences in relation to weight increase or feed efficiency.

Montilla et al. (1969) studied in 1-day-old Vantress × White Rock chicks the effect of incorporating 0, 15, and 30% sweet cassava root flour in rations whose principal protein sources were the following flours: sesame, cotton seed, meat and bone meal, and fish meal. The cassava root flour was obtained from unwashed sun-dried roots (approximately 36 h). The weight increases by the 6th week were very similar: 995 g, 995 g, and 981 g for diets with 0, 15, and 30% cassava root flour, respectively. Feed efficiency decreased in a linear fashion, with values in the same order of 2.03, 2.09, and 2.19; feed consumption increased from 2.020 kg in the basal ration to 2.151 kg at the 30% cassava flour level. The authors suggested that the deterioration in the feed efficiency could be a result of the powdery characteristic that the cassava root flour gave to the rations. Montilla et al. (1970), using the same levels of substitution, added to all the diets 5% animal fat and 5% sugar cane molasses with the object of eliminating the powdery characteristic given by the cassava root flour. At the 8th week, no significant differences in feed consumption, weight increase, or feed efficiency were detected between the treatments. Feeding costs were reduced by 7.4 and 9.8% for the chicks that received rations containing 15 and 30% cassava.

Vogt and Stute (1964) had already observed that better results were obtained when dehydrated cassava root flour was pelleted, and they suggested that the feed intake could be negatively influenced by the excessively fine nature of the flour. Müller et al. (1974), considering the specific weight of a corn-based diet to be 100, found that this value decreased to 81 when 40% cassava root flour was used as a corn substitute, but that it increased to 109 when the feed was pelleted. Chou and Müller (1972) substituted pelleted cassava root flour for corn flour at levels of up to 58%, and found that this substitution was possible provided that the diets were duly balanced with regard to other nutrients. They emphasized that toxic or growth-retarding factors were not observed. Palisse and Barratou (1974) re-

placed 23% of the corn or wheat with 20% cassava root flour, 2% animal fat, 1% soybean flour, and 60 g methionine, without encountering significant differences with respect to feed consumption, weight gain, and feed efficiency, provided that the rations were prepared in the form of pellets.

Armas and Chicco (1973) replaced corn with cassava flour in broiler diets containing corn flour, soybean flour, sesame flour, meat meal, and fish meal. The cassava flour was incorporated at levels of 18, 36, and 54% in the diets (which were isocaloric and isoproteinaceous), and they found no significant differences with respect to weight increase and feed efficiency, although with the diet containing 54% cassava flour the weight increase was reduced by 8.1%. The fact that the diets contained 8 or 16% animal protein, or were supplemented with 0.3% methionine and 0.3% lysine, did not affect the results. According to Sebastia et al. (1973), feed consumption was not affected in broilers by the substitution of up to 50% of the sorghum by cassava root flour. They found a significant weight gain difference, the best diet being that in which 30% of the sorghum was substituted by cassava root flour; higher levels of substitution gave rise to a marked deterioration in weight increase and feed efficiency.

Montilla et al. (1975) partially (30% of the diet) and totally (37% of the ration) replaced corn flour with "sour" cassava root flour (785 ppm HCN in fresh cassava, and 50 ppm in the flour). In both cases 11% of the corn had been replaced by 9% sugar cane molasses and 2% animal fat to eliminate the powdery characteristic of the rations. These rations, given to 1-day-old Vantress × White Rock chicks, resulted in very similar weight gains at the 4th week in the case of diets containing 0 and 30% "sour" cassava flour; at the 37% level the weight gain dropped by 9.0% (highly significant). The same authors compared base rations (starters and finishers) with rations containing 30% "sweet" cassava root flour (0 ppm HCN) or 30% "sour" cassava root flour (50 ppm HCN) (Table 1).

The "sour" cassava behaved in a slightly inferior manner with regard to weight increase and feed efficiency, probably because of its HCN content (50 ppm). It would appear that, even accepting the affirmations by Tejada and Brambila (1969) and Jalaludin and Yin (1972) that birds (*Gallus*) are exceptionally resistant to HCN intoxication, it is necessary to obtain (by adequate processing) a product that does not contain HCN, or which contains it in a very low proportion. It is worth noting that the cassava flour used in all the experiments carried out by Montilla was sun dried.

Phuah and Hutagalung (1974) provided meat-type chicks with rations having three protein levels (19, 22, and 25%) and three cassava flour levels (0, 20, and 40%) over the period of 3–6 weeks of age. After 3–6 weeks of age they gave the same levels of cassava but reduced the protein levels to 17, 20, and 23%. They found that the percentage carcass yield (dry basis) and carcass yield protein were significantly higher, and that the production of fat was lower with 20% cassava root flour. The digestibility of the protein was reduced, and that of the fat was increased, when the percentage of cassava was increased in the diet. They concluded that cassava flour had no adverse effects when the diet was supplemented with methionine, lysine, and palm oil.

Cassava Leaf and Foliage

Miranda et al. (1957) conducted two experiments comparing chick rations containing 5% of either alfalfa (*Medicago sativa*) hay, tropical kudzu (*Pueraria javanica*) hay, cassava (*Manihot esculenta*) hay, or *Desmodium discolor hay*. The body weights obtained with all the rations at 8 and 12 weeks did not differ significantly. They concluded that any of the four hays produced satisfactory results under the conditions of the experiments.

Ross and Enriquez (1969) studied the effects of incorporating cassava leaf meal at levels of up to 20% in rations for 1-day-old male Leghorn chicks. The fresh material utilized in the first two experiments was from plants 11–15 months old, and from younger plants for subsequent experiments. The flour prepared with these materials had a protein content of 14.8% in the first case, and approximately 18.0% in the others. The flour was prepared by drying the leaves overnight in a drying chamber at 50 °C. The HCN content of one of the flours utilized was 554 ppm. From the first experiments it was concluded that cassava leaf flour depressed body weight increase and feed efficiency when it was incorporated at levels higher than 3%. Supplementation with 0.15% methionine and 3% maize oil overcame the adverse effects at all levels. According to

Table 1. Results after 6 and 8 weeks of the substitution of 30% "sweet" or 30% "sour" cassava root meal in chick diets.

	6 weeks		8 weeks	
	Weight increment (kg)	Feed efficiency	Weight increment (kg)	Feed efficiency
0% cassava	1.056	2.052	1.518	2.313
30% "sweet"	1.034	2.177	1.501	2.448
30% "sour"	1.014	2.245	1.459	2.490

these authors, methionine appears to be the first limiting factor and energy the second one in chick diets containing cassava leaf flour. A marginal methionine deficiency may have been responsible for some of the growth depression, although the presence of appreciable quantities of cyanogenetic glucoside in cassava leaves suggests that cyanide toxicity may have been responsible for a relative methionine deficiency. Because the growth effect from supplemental methionine was greater than could be explained from the methionine content of the rations, the hypothesis was advanced that cassava leaf rations required methionine to provide additional sulfur for cyanide detoxification. The addition of 0.15% sodium thiosulfate to the 20% cassava leaf ration significantly improved growth, supporting this hypothesis.

Agudu (1972) compared cassava (*Manihot utilissima*) and Madras thorn (*Pithecellobium dulce*) leaf flours, a synthetic xanthophyll material, and two sources of yellow corn as sources of yolk pigments in White Leghorn pullets. Cassava leaf flour appears to be a good source of pigments.

Montilla et al. (1973) found no significant differences in body weight gain, feed efficiency, or pigmentation effect when they compared 2.5% cassava foliage flour (from 3-month-old plants) with the same level of alfalfa flour in broiler rations.

Siriwardene and Ranaweera (1974) prepared a flour including leaf (blade), leaf stalks, and younger stems. The flour thus prepared contained 22.3% protein and 16.8% crude fibre and was incorporated in rations for 1-week-old chicks at levels substitution of 0, 3, 5, and 10% for coconut meal. Differences in body weight increment and feed efficiency were not significant.

Montilla et al. (1976) prepared broiler rations in which cassava foliage flour was incorporated at levels of 10, 20, and 30%. Each 10% of cassava foliage replaced 7.5% of a sesame–cotton seed flour mix (3:1) and 2.5% maize. Diets were fed as either mash or pellets. When mash diets were used, body weight increment and feed efficiency were adversely affected at each level of cassava foliage substitution from 0 to 6 weeks of age. Body weight gains were similar for all treatments for the 6–10-week-old birds. Feed efficiency in the 6–10-week-old groups gave similar results except at the 30% level, in which the response was poor. Pelleted diets up to 20% showed good improvement in body weight increments; birds reaching market weights at 8 weeks of age. Feed efficiency was poor in the pelleted diets, probably because a high capacity pelleting machine was used to process small quantities of feed. Steam injection could not be controlled and the pelletization occurred mostly dry, probably destroying and/or impairing some nutrients. The results suggest that cassava foliage flour can be incorporated at relatively high levels in pelleted broiler rations. These results, and research in progress, suggest that oil-seed meals can be reduced by up to 30% by using cassava foliage flour at levels between 16 and 20%. In the cassava foliage flour used by the author HCN was not detected, although the fresh material had about 500 ppm; whereas, the flour used by Enriquez and Ross (1969) had 554 ppm. The difference may be in the processing: sun-drying versus drying chamber at 50 °C.

Hutagalung et al. (1974) using 2-week-old meat-type chicks studied the effects of incorporating in a basal diet (a) (principal ingredients were soybean flour and corn flour) the following: 10% (b) and 20% (c) cassava leaf flour; 20% (d) and 40% (e) cassava root flour; 10% cassava leaf flour and 30% of cassava root flour (f); and 15% cassava leaf flour and 30% cassava root flour (g). The body weight increments were: 18.2; 15.7; 15.2; 18.4; 16.0; 15.8; and 15.7 g/day for diets a, b, c, d,

e, f, and g, respectively. In the same order, the feed efficiency was: 3.12; 3.36; 3.81; 3.14; 3.24; 3.64; and 3.81. The chicks receiving the cassava leaf flour did not consume enough feed to meet their nutrient requirements, particularly energy and protein, probably because of a reduction in nutrient density. As well, they referred to the incomplete elimination of the growth depressing factor in the cassava leaf flour.

The estimated cereal requirements for Venezuela are about 6.2 million tonnes (about 2.2 million tonnes for poultry and swine feeding). With actual cereal crop yields of about 1.3 tonnes/ha (which is similar to that obtained in most tropical countries), this would require the planting of about 4.6 million ha. If cassava and sugar cane (with rice as the main cereal crop) were used on a large scale the required area for planting would be reduced to less than 1 million ha. Good cassava varieties, with proper planting techniques, yield 10 tonnes/ha/year of dry roots and 30 tonnes/ha/year of cassava foliage flour, which would produce (at 20% protein) 6 tonnes of protein/ha/year. At the present time sugar cane is yielding 7 tonnes of sugar and about 3.5 tonnes of molasses/ha/year, and rice yields approximately 3.0 tonnes/ha/year.

The following points are emphasized:

(1) Cassava root flour with which research on broiler nutrition has been carried out has not been uniform either in composition or in method of processing. Whole cassava root flour, from roots washed or unwashed, peeled or unpeeled, oven-dried following crushing to remove water, dried in driers and sun-dried respectively have been used. If to this are added the variations among varieties with respect to chemical composition, it is difficult to expect that the results would be homogenic. It is suggested that attempts be made to experiment with, and define the composition of, whole washed sun dried cassava root flour and with whole flour dehydrated by the D'Andrea process which seems to be the most appropriate, at least for the developing countries.

(2) Most of the research carried out during the last 10 years shows that cassava flour can be incorporated into broiler rations at levels of up to 30%, in substitution of cereals. As is the case with any energy source, it is necessary that the diet be balanced.

(3) Supplementation with methionine seems necessary only when the basic protein source is soybean flour and/or appreciable amounts of HCN are found in the flour.

(4) When the diets are prepared in the form of pellets cassava root flour can be incorporated into broiler diets at levels of 50% or more. The beneficial effect of pelleting is explained by the consideration that the digestive tract of birds is short and of little physical capacity; for these reasons, in their feeds, one not only has to consider the concentration of nutrients per unit of weight, but also per unit of volume. Cassava flour is a material of relatively low density, a limitation which is overcome by pelletization.

(5) When pelletization is not possible, molasses and/or animal or vegetable fats must be incorporated into the diet to eliminate the powdery characteristic that cassava flour confers upon the rations, which can adversely affect feed consumption.

(6) It appears impractical to think of collecting and processing the leaves of the cassava plant alone. However, it seems more logical to consider cassava foliage as distinct from cassava roots and harvesting it at time intervals of between 60 and 75 days.

(7) It appears possible to utilize up to 50% cassava root flour and 20% cassava foliage flour in pelleted broiler diets, these amounts replacing almost all the cereals and up to as much as one third of the oil-seed meals.

(8) It is important that broiler feeding experiments utilizing cassava products should not only evaluate body weight increase and feed efficiency, but also state the product yield in terms of production per hectare (tonnes/ha) as this is a more logical approach to an agricultural activity. Countries in temperate areas are obtaining between 1.5 and 2.0 tonnes of broilers (live weight) per hectare using cereals and soybean flour as the chief ingredients of the diets. These levels of production could be achieved, and even surpassed, in tropical areas if products from cassava and other high yielding tropical crops were to be used. Currently, in the tropical areas of the world, classical broiler diets produce slightly over 0.4 tonnes of broilers per hectare.

Some areas of research which should be emphasized are:

(1) Drying methods for roots from "sour" cassava varieties and for foliage of all varieties, to render the feedstuffs innocuous.

(2) Processing and utilization of mixed cassava root and foliage to take advantage of the high enzyme concentration (for HCN liber-

ation) in the foliage. This would provide a product relatively high in energy and with approximately 9% protein, when combined in the proportion of 1:1 on a fresh basis.

(3) Levels and combinations of cassava root flour and cassava leaf flour, and of both with other ingredients including amino acids, vitamins, and minerals, for the periods of the broiler production cycle (growing and finishing).

(4) HCN removal from cassava foliage is total when it is sun dried, but not when a drying chamber (50 °C) is used. Studies should be carried out on leaving the fresh previously cut material overnight, as this would help in obtaining innocuous products when fast drying is used.

(5) The economics of the whole production process comparing classical cereals-soybean flour diets with diets based on cassava products should be reviewed. The author strongly believes that even when a deterioration of 10% occurs in body weight increase and feed efficiency, diets based on cassava products are an economically feasible proposition in developing countries.

Cassava in the Nutrition of Layers

T. A. Omole[1]

The high price of cereal grains and their low production level in the tropics have led to an increase in the price of eggs. There is an urgent need for an alternate source of dietary energy for egg production. Cassava yields several times more energy per hectare than maize or guinea corn and poses fewer storage problems. As a result of the release of HCN from cassava, a close look is taken in this paper into its effect on nutrient availability, nutrient utilization, efficiency of production, and egg quality of layers fed cassava diets. The irreversible reaction of hydroxycobalamin with cyanide to form cyanocobalamin is beneficial in promoting the release of the available form of vitamin B_{12} in the process of cyanide detoxication by the layers. The activity of the shell gland of the layer may be depressed by the action of HCN, which combines with hemoglobin to form a nonoxygen carrying compound cyanohemoglobin. Also, cytochrome oxidase activity may be reduced as HCN forms a reversible complex with the copper of the oxidase system. Iodine availability is similarly hampered in layers fed cassava diets. The result of these reactions may be low hatchability, prolonged hatching time, and depressed production rate. However, up to 60% cassava flour meal may be fed to layers if the diet is well balanced in other nutrients. The use of 0.5% cassava leaf meal may remove the yolk colour problem; whereas, egg weight may be increased by the use of added fat and synthetic methionine. Since cassava is high in ascorbic acid, egg shell thickness may not be a problem at high temperatures. More extensive studies are recommended.

Cereal grains supply the bulk of the energy required in most of the rations used for egg production today. Because of the high yield of cereal grains obtainable per hectare in the developed countries of the world, grain supply is adequate to meet the quantities required for human consumption and for animal feeding. However, in the less developed countries, cereal grains are in high demand for human use and the production has never been adequate to meet the needs of the increasing population, consequently there is no excess grain for feeding livestock. Enormous losses and wastage occur during harvesting; whereas, damage due to insects during storage further reduces most of the advantages derivable from the use of newer hybrids and developing technology. The net result is a considerable increase in the market price for cereal grains and an equally high increase in the price of eggs. There is an urgent need to seek an alternative source of energy for use in egg production enterprises in the developing part of the world.

Of all the tropical farm crops, cassava is the most productive in terms of its energy yield. Data from Nigeria indicate that cassava yields 13 times more energy per hectare than maize or guinea corn (Oyenuga 1961). Apart from its ease of propagation and economy of production, cassava is relatively free from pests and poses comparatively fewer storage problems compared to maize.

The root and leaf material are two nutritionally valuable products that can be obtained from the cassava plant. The cassava root has an estimated average composition of 60–65% moisture, 30–35% carbohydrate, 0.2–0.6% ether extract, 1–2% crude protein, and a relatively low content of minerals and vitamins. It is, however, fairly rich in calcium and ascorbic acid and contains nutritionally significant amounts of thiamine, riboflavin, and niacin. The leaves on the other hand have one of the highest protein levels of any green plant material. Proximate analysis values are: 77% moisture; 8.2% crude protein; 3.3% NFE; 1.2% ether extract; and 7.2% crude fibre (Johnson and Raymond 1965). Rogers and Milner (1963) showed that on a dry matter basis, protein content of leaves in Brazilian varieties of cassava is within a range of 17.8 and 34.8% and that from Jamaican varieties 18.5–32.4%. Oyenuga (1968) indicated that cassava leaves from varieties in Nigeria averaged 14.7% protein, 8.4% ether extract, and 16.1% total ash. Eggum (1970) analyzed the amino acid content of leaves of three varieties from Nigeria and found that they averaged 6% lysine, 2% methionine, 11% aspartic acid, 6% valine, 5.5% arginine, and 2.2% tryptophan. True digestibility was 73%.

However, because of the release from cassava of hydrocyanic acid (HCN) through acid

[1]Department of Animal Science, University of Ife, Ile-Ife, Nigeria.

or enzymatic hydrolysis of the cyanogenic glucosides, linamarin, and lotaustralin (Nartey 1968) a careful examination is required of the effect of HCN on nutrient availability, nutrient utilization, efficiency of egg production, and egg quality of layers fed cassava diets.

Nutrient Availability and Utilization

The nutritional implication of HCN has been reviewed (Oke 1969). There is considerable evidence that vitamin B_{12} (cyanocobalamin) possibly in the form of vitamin B_{12a} (hydroxocobalamin) plays an important role in the detoxication of cyanide in the body (Mushett et al. 1952; Smith and Duckett 1965; Wokes and Picard 1955). Kaczka et al. (1950) observed that in the presence of light, vitamin B_{12} is converted to vitamin B_{12a} that can react with cyanide to regenerate vitamin B_{12}. The reaction of vitamin B_{12a} with cyanide to form vitamin B_{12} is irreversible and so this may be beneficial in promoting the release of the available form of vitamin B_{12} in the process of cyanide detoxication by the laying bird. Ewing (1963) reported a close relationship between increasing levels of vitamin B_{12} and hatchability in laying birds. Evidence indicating that vitamin B_{12} plays an important role in the performance of laying hens has been produced by Couch et al. (1950).

Some of the symptoms of HCN poisoning can be explained on the basis of its affinity for metal ions such as copper and iron. It combines with hemoglobin to form cyanohemoglobin, which is not an oxygen carrier. The effect of low oxygen transport on the shell gland of hens is reduced oxygen uptake. The shell gland of the laying bird has several functions. Besides the action of the muscle to move and expel the egg, it takes care of the secretion and possibly the synthesis of organic materials like the shell matrix, the true cuticle, and ooporphyrins. It is also responsible for the secretion of inorganic materials for the plumping fluid and for shell formation. El-Jack and Lake (1967) observed that the calcium content in the uterin fluids of laying hens is higher than the calcium content of the blood, which suggests an active transport of this ion — a system requiring an adequate supply of oxygen. Beuving (1970) indicated that a high oxygen uptake is required by the shell gland of the laying hen to effectively function.

HCN also forms a reversible combination with the copper of the cytochrome oxidase system, the terminal oxidase in the electron transport mechanism from which high energy phosphate bonds are derived. Any alteration in the form of the copper content of the cytochrome oxidase will inhibit its function as an oxidative enzyme in energy metabolism. This probably explains in part the results of some workers (Enriquez and Ross 1967; Jalaludin and Leong 1973; Chou et al. 1973; Sonaiya et al. 1976; and Montilla, personal communication 1977) who observed depressed efficiency of feed utilization as a result of feeding high levels of cassava meal to different classes of livestock.

Ermans et al. (1973) indicated that the main effect of prolonged consumption of cassava on rats is a marked depletion of the iodine stores; the degree of this depletion was strikingly severe in the absence of iodine supplementation. They further observed that abnormalities induced on the thyroid function by cassava consumption could not be distinguished qualitatively from those related to an insufficient iodine intake. The implication of this in the layers is that reproduction is related to thyroid function, possibly through the gonads. Calcification is also affected in some cases of dysfunction, possibly through the parathyroid glands (Ewing 1963). There is sufficient evidence, however, to show that egg production may not be affected by the iodine content of the ration (Rogler et al. 1961a, 1961b). Hatchability of eggs from hens fed iodine-deficient diets is greatly reduced and hatching time is prolonged. The weights of 18-day embryos from hens receiving low levels of iodine were also significantly lowered (Rogler et al. 1961b). This suggests that breeding hens fed high levels of cassava-based rations may show slow hatchability of eggs, but the problem requires study.

Efficiency of Egg Production

Temperton and Dudley (1941) used cassava meal as a substitute for maize meal and ground oats. They observed that laying birds could tolerate up to 40% cassava meal in a dry mash without the ration being unpalatable or causing constipation. Egg production was lower than on ordinary ration, but changes in body weight and mortality rate were similar. Later, as a result of a scarcity of maize in southern Rhodesia during World War II, trials were made in 1943 to test the value of cassava meal and

palm kernel meal for growing chickens and laying hens; cassava meal proved to be a good substitute for maize and palm kernel meal (S.R. Poultry Report 1943).

An increase of 19.2% in egg production was reported when Falanghe (1949) replaced wheat bran with cassava meal and rice bran. A more balanced nutrient was probably achieved by the feeding of both cassava meal and rice bran in the diet of the layers. Fangauf (1955) suggested that cassava meal should not be fed beyond 25% in the diets of laying birds; the consequence of higher levels being decreased egg production. Levels similar to those suggested by Fangauf were later fed by Mantel (1961). In his experiment, cassava meal was fed to layers at 0, 8, 16, and 24% for 317 days. All the diets had about 16.3% digestible protein and the respective productive energy contents were 1722, 1699, 1675, and 1651 kcal/kg with ratios of percentage crude protein to kcal productive energy of 1:83.6, 1:82.5, 1:81.3 and 1:80.5. There was no effect of the cassava diet on average daily intake, and feed utilization was improved by 14.7% in the diet containing 16% cassava. Egg production was not affected by any of the cassava levels. Vogt (1966) concluded that 20% cassava meal may be employed in the diets of laying birds as long as the lower protein content of cassava meal is compensated by high levels of protein feedstuffs.

In more recent studies, higher levels of cassava meal have been used in the diet of layers. Pillai et al. (1968) replaced 50% of ragi flour (*Eleusine corocana*) by cassava spent pulp, a fibrous waste of starch extraction, in the diet of laying hens. They observed a significant 12% increase in egg laying even though the two diets were isoproteic and isocaloric, but were unable to explain the cause of improvement resulting from the inclusion of tapioca in the diet. Similarly, Enriquez and Ross (1972) fed cassava root meal as up to 50% of the ration of White Leghorn pullets and observed no adverse effects on egg production and efficiency of feed conversion. Hamid and Jalaludin (1972) replaced maize with cassava root meal in the diets for laying birds at levels 0, 20, 40, 60, and 76%. A nonsignificant increase in feed consumption and egg production was reported up to the 60% level of substitution. Supplementation of the 76% cassava meal with 0.15% methionine gave no significant improvement in performance. Supplementation with 0.30% methionine, however, gave a significant increase in egg production. They concluded from this study that cassava could be successfully used to replace maize up to a level of 60% in the diets of laying birds, but that above that, there may be difficulty in maintaining the protein content of the ration.

Jalaludin and Leong (1973) in two separate experiments observed that low dietary levels of cassava meal (5, 10%) had no deleterious effect on egg production and efficiency of feed conversion, but 50 or 60% levels of cassava root meal tended to decrease production and feed efficiency. They further observed that the depressing effect of high dietary levels of cassava meal could be overcome by supplementing with fish meal.

In a 40-week study by Eshiett and Ademosun (1976), White Leghorn pullets were fed cassava meal from 1 week of age through the first 4 months of laying. During the initial period of 1–6 weeks, a low level of 15% dietary cassava was fed. Half of the birds receiving 15% cassava meal were fed 30% cassava between 7 and 12 weeks of age; whereas, the remaining half continued to receive the 15% cassava through the laying period. Beyond 12 weeks, half previously receiving 30% were fed 40% cassava meal. Throughout the growing phases of the pullets, varying levels of dietary cassava did not affect feed conversion, egg production, or egg weight.

Cassava Peel Meal

Most of the studies reported herein have used cassava root meal in their investigations, and in many cases the roots were peeled before being made into flour. However, the peel has not been thoroughly explored at present. Chemical analysis shows that the peel is richer than the pulp in crude protein and is also high in total ash and crude fibre (Table 1). Its high fat content may be an advantage in overcoming some of the egg quality problems associated with high dietary levels of cassava flour meal. Using peeled cassava for human food, the production of starch for making biscuits, beer, industrial alcohol, and glucose, means an abundant amount of cassava peel may go to waste. Like the pulp, the single major factor militating against the use of the peel is its HCN content. Oyenuga and Amazigo (1957) found that peels of six Nigerian varieties contained five to ten times the concentration of HCN found in the pulp. However, Carmody (1900)

Table 1. Proximate composition (%) of cassava root meal (from peeled cassava) (CRM), cassava peel meal (CPM), and yellow corn meal (YCM).[1]

	CRM	CPM	YCM
Dry matter	28.50	27.94	90.38
Crude protein	2.58	5.29	10.65
Ether extract	0.48	1.18	4.09
Crude fibre	0.43	20.97	1.32
NFE	94.12	66.63	82.56
Total ash	2.41	5.93	3.68

[1]Source: Oyenuga 1968.

pointed out that although the sweet type may contain as much acid as the bitter type, the distribution of the acid is different. A high concentration of the HCN is confined to the skin and outer cortical layer in the sweet type; whereas, the acid is more evenly distributed in the root of the bitter varieties. It appears that the main problem lies with the type of cassava used.

Part of the problem of toxicity may be overcome by drying. If linamarin itself is not toxic, presumably the heating process during drying may be sufficient to denature the hydrolytic enzyme and so prevent the release of free HCN. Razafimahery (1953) indicated that about two-thirds of the HCN present in cassava was lost during sun drying for 7 days.

Egg Quality

Hamid and Jalaludin (1972) observed that egg yolks became progressively whiter as cassava meal increased from 20 to 60% of the ration. Similar results were obtained by Enriquez and Ross (1972). Two factors are likely to be responsible for poor yolk colour: (1) the absence of pigmenting xanthophyll; and (2) the low fat content of cassava flour meal, which indicates a low level of carotene. However, Guimaraes and Cresta de Barros (1972) suggested that the carotene level may be of less significance in areas where yellow cassava is produced.

Agudu (1972) compared cassava leaf meal, madras thorn leaf meal, a synthetic xanthophyll, and two types of corn as sources of egg yolk pigment in four separate experiments using White Leghorn strain-cross pullets. He observed that cassava leaf meal had higher total (605 mg/kg) and pigmenting xanthophyll (508 mg/kg) contents than madras thorn leaf meal and commercial xanthophyll. Visual colour score was also higher in eggs supplemented with cassava leaf meal (CLM) than the madras thorn leaf (MTL) meal or the commercial xanthophyll (CX). The average visual colour scores were: white corn 1.0; 0.25% MTL 3.0; 0.50% MTL 4.0; 0.25% CLM 4.9; 0.50% CLM 5.4; yellow corn 3.3; and 0.5% CX 1.7. Inclusion of about 0.5% cassava leaf meal will remove the problem of white yolk colour associated with high levels of cassava in the diets of laying birds.

The low fat content of cassava meal as compared with maize may have some effect on egg weight. Hens fed purified diets lay smaller sized eggs than similar hens fed practical ration. This was true whether isolated soybean protein or fish meal served as the only protein source of the purified diet (Ewing 1963). Studies have been conducted with White Leghorn hens using a basal diet consisting of fish meal, glucose, cellulose, vitamins, and minerals. Treatments included substitution of corn starch, and yellow corn for glucose and increasing the protein level of the diet from 15 to 20%. Only the addition of yellow corn consistently increased egg weight. In another experiment, corn oil was determined as the factor responsible for increasing egg weight (Jensen et al. 1957). This may be significant where most or all of the maize is replaced by cassava meal. Scott et al. (1969) indicated that a striking reduction in egg size can be produced by a linoleic acid deficiency in the ration. In a severe deficiency, eggs laid by mature hens may weigh only about 40 g compared with a weight of 60 g for eggs from control hens. Hildith and Williams (1964) have analyzed large samples of maize fat and found that generally it contains 60.8% linoleic acid; whereas, Hudson and Ogunsua (1974) obtained a value of 14.6% linoleic acid in cassava tuber fat. Analyses by Janssen and Terpstra (1972) indicated that yellow maize contained 42 g fat/kg dry matter and that cassava contained 5 g fat/kg dry matter. Under practical conditions, linoleic acid may be submarginal in cassava diets containing low levels of yellow corn and no added fat. Improvement in egg size from sources of linoleic acid have been observed when birds are fed diets based primarily on barley, wheat, or milo (Scott et al. 1969).

Besides the effect of low linoleate in cassava diets, egg weight problems may be complicated by an inadequate supply of dietary methionine. Oyenuga (1968) reported the methionine con-

tent of maize as 194 mg/16 gN, and that of cassava as 63 mg/16 gN. The total methionine content of high level cassava diets unsupplemented with synthetic methionine may be too low for normal egg size in laying birds. Scott et al. (1969) indicated that the most important nutritional factors known to affect egg size are the protein and amino acid adequacy of the diet. Since about 50% of the dry matter of an egg is protein, the supply of amino acids for protein synthesis is critical for egg production. When the supply of either one or several amino acids is low, egg protein with an altered amino acid composition will not be synthesized. Instead, under conditions of mild deficiency, the quantity of protein synthesized may be decreased and in severe dietary deficiency, egg protein synthesis may essentially cease. Often a reduced egg size is the only consequence observed in marginal protein or amino acid deficiency. It is generally accepted that methionine is the first limiting amino acid of laying rations (Ewing 1963). Enriquez and Ross (1972) and Jalaludin and Leong (1973) recorded slight but nonsignificant reductions in egg weight when 50 or 60% cassava meal was fed to laying hens.

It is very unlikely that dietary cassava will have any effect on shell colour. The colour of the shell is largely dependent upon the production of pigments by certain breeds. This is completely unrelated to the nutritional value of the egg and is ordinarily not altered by the nutrition of the layer. Where there is preference about shell colour, additives like nicarbazin may be used for the production of white shells; whereas, high dietary level of chlortetracycline may result in the production of yellow shells. The major concerns of shell quality are thickness and structure. Consumers desire an egg that is as resistant as possible to breakage and to penetration by microorganisms. The addition of vitamin C to the ration will increase shell quality in the case of high environmental temperatures (Thornton and Morenq 1959; Sullivan and Kingan 1962). In a more recent investigation on the effect of vitamin C on the structure and ultrastructure of the egg shell, El-Boushy et al. (1968) reported that vitamin C addition to layer rations resulted in increased shell thickness and improved shell structure. Oyenuga (1968) indicated that the vitamin C content of cassava (35.0 mg/100 g) is over three times as high as that of maize (11.4 mg/100 g) on a dry matter basis. At high levels of cassava feeding, the vitamin C content of the diet should be high enough to improve shell thickness and structure. Enriquez and Ross (1972) demonstrated that shell thickness was increased when 10, 25, or 50% cassava meal was fed to White Leghorn pullets.

Conclusions

Before using cassava extensively in their diets, much more study is required to determine the possible adjustments that might be necessary to meet the nutrient requirement of layers.

The affinity of HCN for metal ions may render both the copper and iron in feed unavailable. Improved processing techniques may reduce the HCN content of cassava meal; however, the need to investigate the copper requirements of cassava-based diets cannot be overemphasized. Jenkins et al. (1970) stimulated growth in pullet chicks by feeding copper above recommended levels in diets based on cereal grains. The rate of energy metabolism may be improved by increasing copper levels; whereas, increasing dietary iron may lead to improved functioning of the shell gland as a result of increased oxygen uptake.

The role of supplemental methionine in cassava diets for laying birds is two-fold: (1) being a sulfur-containing amino acid, methionine may be involved in the detoxication of HCN; and (2) the amino acid distribution of the diet becomes more balanced as cassava is low in this limiting amino acid. The result is a more efficient utilization of dietary protein and increased egg production and egg size. Apart from methionine, the addition of fat will reduce feed dustiness and feed wastage, supply carotene and essential fatty acids especially linoleic acid, and improve egg size.

The use of cassava leaves in laying rations should be encouraged. Apart from its ability to yield good quality protein, it helps to retain yolk colour. In general, further investigation is required to ascertain the effects of cassava meal on various aspects of egg production and quality.

Cassava in the Nutrition of Swine[1]

S. Khajarern,[2] J. M. Khajarern,[2] N. Kitpanit,[2] and Z. O. Müller[3]

A review of the nutritive value of cassava products and the utilization of these products in swine rations is presented. It is generally agreed that cassava root products can be successfully used as an energy source for swine. The products, once properly prepared and carefully balanced for all nutrients, can be used at levels of 40–75% in diets for growing-finishing swine without adversely affecting performance or carcass characteristics. Both the technical and economic aspects of the limitations and the fortifications required for the utilization of the products are discussed. Experimental results at Khon Kaen University have demonstrated that cassava root products at levels as high as 50% and 68–70% can be successfully incorporated in the starting and growing-finishing diets, respectively. The possibility of lowering the protein level in swine rations containing high levels of cassava root meal is suggested because the protein quality, once fortified with methionine, is higher in cassava-based than in cereal-based diets.

At present, cassava (*Manihot* spp.) is one of the most important food crops in the world. The world production of fresh cassava root is reported to be about 105 million tonnes from a cultivated area of some 12 million hectares (FAO 1974). Approximately 90% of the cassava that is produced is used as human food; the rest is for livestock feed and other industrial usages (Coursey and Halliday 1974). The use of cassava root products for livestock feeding was not given much attention until the late-sixties when demand started to increase sharply due to the world feed grain shortage. The significant role of cassava products in animal feed today has resulted from its favourable price compared with feed grains in the European Economic Community (EEC) market. Yet, the real potential for using the product in animal feed has not been fully realized. As a result, cassava is being compounded into animal feeds at a limited level, 5–40% depending on species, age of animal, and country (Anonymous 1968; Nestel 1974).

Cassava Roots: Nutritive Value

The detailed chemical composition of cassava has been reported, but results vary considerably with variety and age of cassava as well as with processing technology (Oyenuga 1955; Johnson and Raymond 1965; Oke 1968; Mesa et al. 1970; Hutagalung 1972; Müller et al. 1972). Cassava root is generally high in carbohydrate and thus ought to be an excellent source of energy for swine. Its carbohydrate contains about 3.2–4.5% crude fibre (CF) and 95–97% nitrogen free extract (NFE) (Hutagalung et al. 1973; Müller et al. 1975). The tuber NFE contains 80% starch and 20% sugar and amides (Vogt 1966). According to Johnson and Raymond (1965), cassava starch is about 20% amylose and 70% amylopectin. Müller et al. (1975) reported that cassava root meal had about one-third the amylolytic activity of maize and that it was highly digestible, yielding digestible energy for pigs of 4000 kcal/kg of dry root meal as compared with 4055 kcal/kg of maize. Similar observations for digestibility and caloric value compared with maize and other cereals have been reported (Yoshida et al. 1966; CIAT 1972; Maust et al. 1972b; Tillon and Serres 1973).

The fat, mineral, and vitamin content of cassava root is low and nutritionally insignificant (Seerly 1972). The protein content of the root is also low making the economic utilization of cassava in swine rations heavily dependent on the price and nutritive value of other protein sources. Cassava root protein is of reasonable quality as far as the proportion of essential amino acids as a percentage of total nitrogen is concerned (Close et al. 1953; Müller et al. 1972, 1975; Hutagalung et al. 1973; Maner 1973). It is generally agreed that methionine, cysteine, and cystine are limiting amino acids in cassava. Detailed studies at CIAT (1972, 1973) have indicated that only 60% of the total nitrogen in the root is derived from amino acids, and that about 1% is in the form of nitrates, nitrites, and hydrocyanic acid. The additional 30–40% of total nitrogen was unidentified. According to these CIAT reports,

[1]Supported by a grant from the International Development Research Centre, Ottawa, Canada.

[2]Department of Animal Science, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand.

[3]Present Address: Asia Research Pte. Ltd., P.O. Box 91, Alexandra, Singapore 3.

about 50% of the total nitrogen is true protein; the rest being amino acid nitrogen in the form of free aspartic and glutamic acids (Maner 1973). In contrast, Oyenuga (1955) reported that 62% of the total nitrogen in cassava roots was true protein. Biological studies with rats and pigs at CIAT (1972, 1973) strongly supported the lower value, as the crude protein was found to be 40% digestible by pigs and 50% utilizable by rats. However, as the cassava protein represents a minute proportion of rat and pig rations, a more important point is that the supplementation of methionine significantly improves the performance of rats and pigs (CIAT 1972). Subsequent studies have repeatedly demonstrated this improvement in performance. They suggest that the amino acid corrects the methionine deficiency per se and donates sulfhydryl (—SH) groups for the detoxication of hydrocyanic acid (Maner and Gomez 1973; CIAT 1975).

The greatest limitation to the use of cassava for livestock feeds is its content of cyanogenetic glucosides, linamarin, and lotaustralin. Toxicity of cassava is caused by hydrocyanic acid (HCN), which is liberated when the glucoside is hydrolyzed by the action of the linamarase enzyme within the plant. The degree of toxicity depends upon the variety, the ecological conditions for growth of the plant, the form of the product being fed, and its processing technology (Coursey 1973). The normal range of HCN content in fresh cassava root is 15–400 ppm (Rogers 1963). Several methods of processing reduce HCN toxicity. Shredding and sun drying of cassava seems to be a practical and effective way to reduce both HCN and glucoside levels (Maner 1973). Cyanide toxicity, which is caused by the prolonged consumption of cassava or by experimental cyanide administration, is known to be associated with human ataxic neuropathy (Osuntokun 1973), goitre, and cretinism in rats (Ekpechi 1973; Ermans et al. 1973). Maner (1973) and CIAT (1973, 1974) demonstrated that pigs voluntarily consume less feed based on bitter cassava compared with sweet cassava regardless of the form of the cassava, fresh (150–250 ppm HCN on a fresh basis) or dried (102 ppm HCN on a dry matter basis), or whether it is free-choice with a protein supplement, or in a mixed ration. The average daily gain of pigs on bitter cassava groups was lower when compared with those on sweet varieties. The efficiency of feed conversion of these pigs was variable due to variation in the amount of protein supplement consumed. In subsequent studies, both in the short and long term, they demonstrated that the urinary excretion of the HCN detoxication product, namely thiocyanate (SCN^-), was accordingly increased with the HCN content of cassava fed (CIAT 1973, 1974). In addition, supplementation with methionine improved the growth performance of the pigs and increased the level of urinary SCN^- excretion. Supplementing iodine in the absence of methionine caused an increase in plasma SCN^-, but supplementation in the presence of methionine decreased it. Sihombing et al. (1971) indicated that pigs fed a corn-soybean meal diet supplemented with 0.5% potassium thiocyanate showed an increase in thyroid weight and a decrease in protein-bound iodine; however, the iodine uptake of the thyroid gland of these pigs was higher than the controls and thus gave no clear indication of goitre. With gestating and lactating swine, workers at CIAT demonstrated that as high as 500 ppm HCN in the diet had no adverse effect on fetus viability or subsequent performance of sow and litter (CIAT 1975). They concluded that HCN at the level present in cassava had little effect on health if fed in diets adequate in protein and iodine. As well, the growth depression that may occur with high cassava-based diet is caused by palatability factors and nonlethal toxicity of HCN; it is necessary to include dietary sulfur to permit cyanide detoxication.

As for nutritive value, cassava is a good substitute for cereals in swine rations provided the ration is compounded with caution. Digestibility of cassava-based diets for swine is reported to be equivalent to or even better than cereal-based diets (Zausch et al. 1968; Chicco et al. 1972). Aumaitre (1969, 1972) demonstrated that cassava improved organic matter digestibility compared with wheat- and barley-based diets by 4–5% and that there was decreased diarrhea in pigs on the cassava-based diet. However, Henry (1971) observed lower digestible protein (81 vs. 86%) and energy (87 vs. 89%) in cassava-based diets compared with maize-based diets for growing-finishing pigs. These values indicate a relatively high digestibility. Maust et al. (1972a) reported lower values for digestible nutrients in pigs fed cassava-based diets containing 29% rice bran, 15.3% CP, and 7.8% CF than those fed maize diets (16.8% CP and 3.1% CF). The protein

quality of cassava-based diets is usually better than cereal-based diets because the cereal protein must be replaced by other proteinaceous foodstuffs having a higher biological value. To get an equivalent protein to that present in maize, Müller et al. (1975) mixed cassava with soybean meal in the proportion 85 to 15%. This mixture has nearly an equivalent amount of methionine and about twice as much lysine and tryptophan as maize; thus the biological value of the protein in the final cassava-based ration should be higher than in cereal-based diets. The actual biological value of the crude protein in cassava-based diets for pigs may be higher than expected. Therefore, it is possible that we are over-feeding protein to experimental pigs on cassava-based diets. It is noteworthy that in all nine experiments conducted by Müller et al. (1972) the cassava-fed pigs performed as well as or, in some cases, even better than those on the maize-based rations regardless of the lower crude protein content of the cassava-based diets. In addition, the most economic weight gain of pigs fed fresh cassava with protein supplement was at the lowest crude protein level (20%), when compared with those containing 30 and 40% protein supplement (CIAT 1974). However, when compounding rations using cassava meal at higher levels, one must be very careful to balance other nutrients such as vitamins, mineral, and fat. These nutrients are present in very minute amounts in cassava roots, and Müller et al. (1975) have cautioned that crude fibre and ash content should be strictly limited in cassava-based diets. Excessive crude fibre in feed for monogastric animals interfers with the utilization of phosphorus and zinc. Maust et al. (1969) and Hutagalung et al. (1973) observed that pigs developed parakeratosis-like symptoms after being fed cassava-based ration for 4 weeks, whereas those on maize rations did not. Zinc levels in these diets were equivalent and adequate for the normal requirements of pigs at this age. The disorders were rapidly eliminated by a onefold increase in supplemented zinc (Maust et al. 1972a; Hutagalung et al. 1973). Maust et al. (1972a) suggested that the zinc deficiency was partially caused by crude fibre and possibly by some additional factor(s) in the cassava-based diet. Crude fibre also causes swine rations to become bulky and dusty (Maner et al. 1969), decreasing feed consumption and inducing irritation of the eyes and respiratory organs (Müller et al. 1975). Müller et al. (1975) strongly recommended the pelletization of swine feed to eliminate dustiness and ensure optimum feed intake. They also suggested that pelletization would improve the digestibility of the starch and crude fibre in the diet. Mercier and Guilbot (1974) demonstrated, by in vitro digestion of maize, that the steam and pressure applied during the pelleting process caused a sevenfold increase in starch digestibility. Similarly, cassava starch and crude fibre may be affected in the same way during pelletization; however, clarification is required. Ash content has received little attention; Müller et al. (1972) noted that excessive ash as well as crude fibre decreased the digestibility of the ration as a whole and limited the choice of other feed ingredients that contained high levels of these nutrients. They suggested the maximum levels of cassava meal of various nutritive profiles that could be incorporated into swine rations (Table 1). Although the values presented in the table are somewhat arbitrary, the range is of practical importance to users of cassava root products. Chemical analysis in our laboratory of some 200 samples of Thai cassava root pellets, the form of over 75% of the cassava products on the world market, revealed that the average crude fibre content was 3.62% and ash was 4.81%. This product belongs to the third grade and should be used at considerably lower levels than the first grade. This is due to the high degree of contamination by soil and other foreign materials in Thai cassava, which is not present in the products being used for feeding trials at CIAT (Maner and associates) and in Malaysia (Hutagalung and associates). The majority of these trials use self-prepared products and their nutritive value is suspected to be relatively high. The significance of these two nutrients in cassava-based rations for swine and other livestock is being evaluated.

Cassava Leaves: Nutritive Value

Cassava leaves may offer a new perspective for livestock and poultry development. The annual yield of foliage is as high as 20 tonnes/ha (Obregon and Juarez 1955), and the dried product is a good source of protein, fibre, minerals, and vitamins. It contains approximately 25.8–27.3% crude protein, 7.6–10.5% fat, 5.7–8.8% ash, 4.8–7.9% crude fibre, and 50.1–51.9% NFE on a dry matter basis. The HCN content of fresh leaves ranges from 46 to 56.5 ppm or 190 to 250 ppm on a dry basis.

Table 1. Suggested levels of cassava root meal in pelleted swine rations.

Quality grade	Content of critical ingredient		Maximum levels of cassava root meal in swine rations (%)		
			Pig starter	Pig grower	Pig finisher
1	Crude fibre (%)	<2.8	40	60	75
	Ash (%)	<2.2			
	DE for pig (Mcal/kg)	<3.68			
2	Crude fibre (%)	<3.5	20	40	60
	Ash (%)	<2.5			
	DE for pig (Mcal/kg)	<3.52			
3	Crude fibre (%)	<5.0	5	30	45
	Ash (%)	<5.0			
	DE for pig (Mcal/kg)	<3.25			
4	Crude fibre	<5.0	0	20	40
	Ash (%)	<5.0			
	DE for pig (Mcal/kg)	<2.77			

Apparently leaf meal is nearly equivalent to alfalfa meal in feed value. In addition, the essential amino acid pattern compares favourably with that of soybean meal. The lysine content is considerably higher (6.33–7.20% of CP) but methionine (1.65–1.71% of CP) and possibly tryptophan (1.47–2.07% of CP) are deficient (Rogers and Milners 1963). Van Veen (1938) reported that approximately 75% of the cassava leaf crude protein was true protein. More recently, Eggum (1970) demonstrated that the digestibility of the leaf protein by rats was 70–80% and that the biological value of the protein was 44–57%. Methionine deficiency and availability seem to cause the low biological value of the protein. He indicated that only 50% of the methionine was available to the rats and that adding methionine to the diet significantly improved the biological value of the leaf protein (80%). Ross and Enriquez (1969) observed a proportional growth depression in chicks and quail fed diets containing 0, 3, 5, 10, 15, or 20% cassava leaf meal. However, when they added sodium thiosulfate, methionine, molasses, and/or vegetable oil to rations containing 15 or 20% leaf meal, growth and feed conversion were significantly improved. Similar improvements in performance were observed when workers at CIAT supplemented methionine and maize oil in leaf-meal diets for rats. With respect to the feeding of cassava meal to pigs, there has been a rather limited amount of work done. Mahendranathan (1971) fed fresh cassava leaves, containing 250–300 ppm HCN (dry basis), to pigs from 8 to 34 weeks of age. He reported that his pigs consumed 1.4–2.3 kg of fresh cassava leaves daily and that there were no clinical symptoms of HCN poisoning. Also, pigs receiving 75% normal levels of basal feed with ad libitum intake of cassava leaves gained as well as those receiving 100% levels, and both groups were significantly superior to a third group that received a 50% leaf basal diet. The efficiency of feed conversion was, however, decreased with decreasing basal feed allowance. The pigs on a 50% basal diet gain most economically. In a short-term study, Lee and Hutagalung (1972) fed piglets, averaging 13.6 kg body weight, diets containing 0, 10, or 20% cassava leaf meal for 4 weeks. They demonstrated that as the leaf meal content of the diets increased, feed intake, daily gain, and feed efficiency were significantly decreased. Supplementation of methionine at a level of 0.20% to the 20% treatment significantly improved performance; whereas, 0.15% thiosulfate supplementation did not. In their subsequent 6-week experiment with a larger pig (30.9 kg), they demonstrated that supplementation of palm oil, molasses, and methionine to a 20% cassava leaf meal diet significantly improved performance compared with those supplemented with molasses or palm oil alone or palm oil with methionine. However, pigs on the basal diet performed significantly better than the rest. There were no clinical symptoms of HCN toxicity in these trials.

Cassava Silage: Nutritive Value

Cassava silage has not been widely used as an energy source for monogastric animals. For swine feeding, Castillo et al. (1963) compared growth performance of finishing swine being fed sweet potato silage and cassava silage with 27.3% protein supplement with those fed 16.9% corn-soybean meal diets. These silages were used as the total energy source in each diet, at a level of 40% of the rations. They demonstrated that the weight gain of the pigs on corn-soybean meal diet was 0.41 kg, which did not significantly differ from that of pigs on cassava silage (0.46 kg) and sweet potato silage diets (0.48 kg). The pigs being fed cassava silage gained most efficiently. They concluded that maize could be entirely replaced by either cassava or sweet potato silage at a level as high as 60% of the ration. Periodic analysis of cassava silage showed some nutrient loss in the runoff solution. Again, it is noteworthy that the pigs on silage diets were overfed protein with the protein supplement. With optimum protein intake, the silage-fed pigs still might not be able to overgrow those on corn-soybean meal diet. More recently, Tillon and Serres (1973) determined the digestibility of cassava silage in swine and indicated that the digestibility of starch was relatively high regardless of the form being fed — fresh, dry, boiled, or silage. The use of silage somewhat reduced the digestibility of minerals. At CIAT, Maner (1973) compared growth performance of growing-finishing pigs fed fresh cassava root, root silage, or whole cassava (root + stalk + leaf) silage plus a protein supplement based on cottonseed meal. He demonstrated that the root silage supported equivalent gain, feed consumption, and feed per gain compared with those produced by fresh cassava root. Pigs on the whole cassava silage, however, did not consume as much or gain as fast as those in the other two groups. The efficiency of feed conversion of pigs in all treatments was not statistically different. He pointed out that the inclusion of stalks in the silage reduced its acceptability to pigs. In a subsequent study (CIAT 1974), ensiled cassava root, mixed or fed free choice with a protein supplement, supported growth performance of pigs comparable to that of pigs fed diets based on maize or fresh root with the protein supplement. When lactating sows were fed free choice ensiled cassava plus a 40% protein supplement during a 35-day lactating period, there were no significant differences in sow weight gain, litter size, or litter weight at weaning when compared with those from sows being fed a maize-soybean meal diet or maize plus a 30% protein supplement. In fact, litter weight at weaning tended to be higher with the cassava silage than with the other two groups (CIAT 1974). Based on available evidence, ensiling seems to be a promising way to utilize cassava in pig rations. Attention should be paid to preventing nutrient loss and, if possible, during the ensiling process one should take advantage of the possibility of enriching the protein content of the product. However, although attempts to raise the protein content in silage by microbial action have been made, they have not yet been successful (Sprung 1974).

Protein-Enriched Cassava

Because of the low protein content of cassava, several investigators have attempted to enrich its protein content by microbial fermentation. Gray and Abou-El-Seoud (1966) indicated that it was possible to increase the protein content of cassava by a factor of 6–8 by fungal fermentation. Subsequently, Stanton and Walbridge (1969) fermented cassava flour with *Rhizopus* fungi and were able to raise the protein content from 0.2 to 4%. More recently, Reade and Gregory (1975) reported a promising technique for the production of microbial protein by fermentation of liquid cassava substrate with high-temperature fungi (*Aspergillus* sp.). With this technique they were able to produce biomass containing 36.9% crude protein (made up of 27.1% amino acid protein). Pilot plant testing and biological evaluation of the product for pig feeding are being conducted at CIAT. At the University of Malaya, protein enrichment by fermentation of solid cassava substrate with *Rhizopus* fungi is being developed. A fermented product with 8–10.5% protein is achieved and techniques for further improvement have been attempted (Varghese and Wong 1976). Evaluation of the fermented product using pigs and poultry is being conducted and initial results with pigs are rather optimistic (Hutagalung and Tan 1976).

Cassava Roots: Feeding Trials

Cassava roots have been used for feeding swine since the early 1900s, from which time attempts made by several workers to evaluate their nutritive value and physiological effects

Table 2. Summary of effect of replacement of cassava-soybean meal for cereals on pig performance. Trial 1.[1]

	Treatments (avg. % cassava)					
	T_1 (0%)	T_2 (17%)	T_3 (33%)	T_4 (49%)	T_5 (65%)	C.V. (%)
Average daily gain (kg)	0.576	0.585	0.532	0.458	0.453	8.14[3,4]
Daily feed consumption (kg)	1.98	2.01	1.95	1.87	1.84	9.58
Feed/gain	3.42	3.39	3.66	4.09	3.97	6.95[3,4]
Feed cost/kg weight gain (Bht)[2]	13.99	13.60	15.96	17.09	17.32	6.96[3,4]

[1]Each figure represents average of 18 pigs on 118-day feeding trial.
[2]Can. $1.0 = Bht. 20.0.
[3]$p < 0.01$.
[4]Linear $p < 0.01$.

on pigs have been continuously reported. The modern view of cassava in swine nutrition originated with the report of Oyenuga and Opeke in 1957 (Nestel 1974). Comprehensive reviews have been done by several investigators (Seerly 1972; and Maner 1973). With respect to the evaluation of the effect of cassava root products on the growth performance and carcass of growing-finishing pigs, three experiments were done during 1975–76. The purpose was to evaluate the feeding value of Thai cassava root products, which were known to be low in quality and high in adulterations, and subsequently to establish the maximum economic level of incorporating cassava products of each quality into growing-finishing diets. Finally, a general pattern of fortification to enable maximum utilization of each quality product was to be worked out.

In the first trial, 90 pigs averaging 24.53 kg body weight were used in a randomized complete block experiment. There were five treatments and six replications. Three pigs in each pen were fed mash diets containing cassava levels of 0, 17, 33, 49, and 65% until they reached an average body weight of 95 kg. The energy sources of the 0% control diet were rice bran, broken rice, and maize. The levels of crude protein were 18, 14, and 13% for 25–35, 35–60, and 60–95 kg body weight, respectively. The results are summarized in Table 2.

As the cassava content of the diet increased from 0 to 65% pigs grew at progressively slower rates and required more feed per kilogram gain. The cost of feed per kilogram gain followed a similar pattern. Daily feed consumption, although it did not significantly differ among treatments, tended to decrease with an increase of dietary cassava. Physical examination of the high cassava-based diets in this experiment indicated that they were light, fluffy, and dusty, which may be a major cause of the reduced feed intake of pigs in treatments 4 and 5. The effect of physical properties of the diet on feed consumption of pigs was demonstrated by Henry (1971) and Müller et al. (1972) who indicated that mash cassava-based diets were disliked by pigs and that the powdered starch, which is present at a higher level in mash diets, produced ulcerogenic effects upon the gastric mucosa and probably induced a lower digestibility and efficiency of feed conversion. The HCN content of the cassava used was suspected to be low, and the exact value was not determined. This is because the cassava used was sun dried and much of the HCN should have been eliminated (Maner 1973). Methionine was supplemented at 0.1% to all diets in this experiment, and in addition, soybean meal was used for protein balance. Fish meal, which was used as a source of protein, was held constant for all treatments (average of three growth periods 6.7%). As far as the normal methionine requirement, the calculated level was not deficient; however, with high cassava content in the feed it would be inadequate. The adequate level of supplemented methionine in cassava diets was demonstrated by Maner and Gomez (1973) to be at least 0.2%.

In two subsequent trials, cassava root pellets of moderate quality (3.5% CF, 3.2% ash, and 76.7% NFE) were substituted for maize or a cereal mixture (maize + rice polishing + broken rice) in the growing and finishing pig rations. The cereal-based diets were fed as a mash, whereas those based on cassava were in pellet form. The substitutional patterns of cassava for cereals and the specific weight of each diet are given in Table 3.

Table 3. Substitutional patterns of cassava for cereals and the specific weight of the experimental diets.[1]

	Trial 2			Trial 3		
Treatment No:	1 (maize)	2	3	1 (cereals)	2	3
Subst. level/live weight (%)						
17–35 kg	0	30	60[2]	0	30	50
35–60 kg	0	40	70	0	38	68
60–100 kg	0	60	70	0	60	70
Specific weight of diets						
17–35 kg	0.641	0.661	0.615	0.603	0.655	0.621
35–60 kg	0.604	0.622	0.631	0.625	0.640	0.666
60–100 kg	0.619	0.627	0.601	0.692	0.597	0.629

[1]All diets, except trial 2, treatment 3, 17–35 kg, were isonitrogeneous and isocaloric within trial and live weight range.
[2]Lower protein (18.4 vs. 21.0) and digestible energy (3.25 vs. 3.50 Mcal/kg) than the rest within trial and live weight range.

Table 4. Summarized effects of cassava feeding on growth performance of growing-finishing pigs.

	Trial 2				Trial 3			
	T_1	T_2	T_3	C.V. (%)	T_1	T_2	T_3	C.V. (%)
Average daily gain (kg)	0.436[1]	0.498[2]	0.464[1,2]	5.86	0.516	0.524	0.509	8.43
Daily feed consumption (kg)	1.46	1.52	1.46	4.68	1.78	1.89	1.78	10.00
Feed/gain	3.21	3.13	3.15	6.72	3.46	3.64	3.51	4.07
Feed cost/kg gain (Bht)	10.21	10.06	9.69	5.00	11.76	12.01	11.25	4.04

[1,2]Means bearing different superscripts differ significantly ($p < 0.05$).

Table 5. Summarized effects of cassava feeding on carcass characteristics of market pigs.

	Trial 2				Trial 3			
	T_1	T_2	T_3	C.V. (%)	T_1	T_2	T_3	C.V. (%)
Dressing (%)	70.74	73.46	73.91	4.28	73.20[1]	73.40[1]	71.10[2]	0.73
Carcass length (cm)	84.79[1]	83.69[2]	80.70[2]	3.20	80.77	80.87	81.53	2.65
Back fat thickness (cm)	2.62	2.82	3.12	15.64	3.07[1]	2.69[2]	2.90[1,2]	7.49
Iodine number of leaf fat	52.85[1]	50.30[1,2]	44.30[2]	11.12	52.07	51.53	50.33	7.99
Stomach wt. (kg)	0.57	0.59	0.53	13.12	1.14	1.09	1.10	11.82
Liver wt. (kg)	2.39[1]	1.85[1,2]	1.81[2]	18.45	3.24	3.37	3.49	9.81
Loin eye area (cm^2)[3]	30.45[1]	26.45[2]	30.07[1]	7.85	30.45	28.90	29.81	11.79

[1,2]The means within same row and trial bearing different superscripts differ significantly ($p < 0.05$).
[3]Measurement made between the 11th and 12th ribs.

In each trial, 45 pigs were penned in groups of three and each treatment had five replications. All experimental diets were offered ad libitum. Pigs were fed the diets until they reached an average live weight within the group of 96–105 kg; one of the three was then slaughtered for carcass evaluation and analysis of selected tissues. The results for growth performance and carcass quality are given in Tables 4 and 5. All data were subjected to analysis of variance and Duncan's new multiple range test (Steel and Torrie 1960).

Although the average daily gain of the pigs was somewhat lower than the optimum desirable level, the treatment comparison demonstrated that cassava root meal could be as good an energy source for pigs as conventional cereals. All pigs in the cassava-fed groups grew as fast, consumed as much, and gained as efficiently as those on the cereal-based diets. Carcass characteristics were somewhat variable: the iodine number of the leaf (abdominal) fat, the stomach weight, and the loin eye area were confirmative between trials, but others such as dressing percentage, carcass length, backfat thickness, and liver weight did not agree well. Proximate analysis of the liver and longissimus dorsi muscle demonstrated that there were no treatment differences in their composition.

Discussion

The growth performance of pigs in these trials indicates that cassava root products of moderate quality can be successfully incorporated into growing-finishing pig diets at as high levels as 50% for 17–35 kg pigs and 68–70% for those of heavier weight. However, it should be noted that the diet must be carefully formulated to balance it for vitamins, minerals, and limiting amino acids. Also, special care must be taken as to the form of the diet, especially when the cassava is of a lower quality (higher CF and ash thus lower digestibility). Diets must be fed in the form promoting optimum feed intake to ensure an adequate supply of digestible nutrients. These points were demonstrated by the equivalence of the daily consumption of pelletized cassava-based diets to the control diets in Trials 2 and 3, which eliminated the poorer growth performance that was shown in Trial 1. This substantiates the statements of Müller et al. (1972, 1975) and of Henry (1971). However, comparable growth of pigs fed mash diets containing high levels of cassava and those fed cereal-based diets has been reported by several investigators (Mesa et al. 1970; Aumaitre 1969, 1972; Hew and Hutagalung 1976). This is possible because these workers used self-prepared, good quality cassava that was more digestible than that used in our study. In fact, the digestible energy levels in the diets of Hew and Hutagalung (1976) ranged from 3.5 Mcal/kg for the maize control to 3.6 Mcal/kg for the 60% cassava diets; whereas, our diets contained 3.5 Mcal/kg (fat supplemented) for 17–35 kg pigs and 3.3 Mcal/kg for heavier pigs. At a higher level (73.8%) of cassava meal in the diets, CIAT (1975) stated that there might be a slight depression in growth performance due to palatability factors and sublethal HCN toxicity.

The cause of the suboptimum weight gain of pigs in these trials was not readily apparent. It was suspected to be caused by the unavailability of some nutrients, especially zinc, because low-grade rice bran was added to the control diets for pigs beyond 35 kg live weight in order to equalize the DE levels. Maust et al. (1969, 1972b) observed depressed Zn availability in diets containing 29% rice bran. Protein quality is another possible cause. Müller et al. (1972) and Hew and Hutagalung (1976) obtained good growth of their pigs when they were fed higher levels of fish meal than used in our diets. The lower fish meal level in our studies might only bring the dietary supply of vitamin B_{12} to a suboptimal level causing poorer performance of all pigs. In addition, the low level of supplemented methionine (0.1% in Trials 1 and 2) might contribute to the poor performance, as caused by lower than expected protein quality. Low levels of methionine and vitamin B_{12} would further suppress the performance of cassava-fed pigs because both nutrients have active roles in cyanide detoxication, in addition to normal requirements (Maner and Gomez 1973). Cassava-fed pigs in Trials 2 and 3 performed as well as those in the control treatment. This should not cause further confusion, but should lead to new prospects. The mixture of 15% soybean meal with 85% cassava meal has about twice as much lysine and tryptophan as maize. If adequate amounts of methionine and B_{12} are supplied, even at the suboptimum level of dietary crude protein, what should the performance of a pig be? Müller et al. (1972) demonstrated that pigs on cassava-soybean meal diets containing lower crude protein than control diets grew as fast and as efficiently as control pigs. Similar results were demonstrated by the pigs in Treatment 3 of Trial 2, which were on a diet containing 2.5% CP and 270 Kcal DE/kg less than the other groups.

Variations in carcass characteristics are partially due to biological variation. Only one pig per pen was slaughtered, thus the data obtained are based on five pigs per treatment instead of 15 pigs. However, there were no detrimental effects on carcass quality due to

cassava consumption. The decreased dressing percentage of pigs in Treatment 3 of Trial 3 is inconsistent with the thicker backfat, as compared with Treatment 2. The shorter carcass of cassava-fed pigs in Trial 2 might be affected by biological variation because it was not confirmed in Trial 3. Several workers have demonstrated that levels of cassava in pig rations do not have a significant influence on carcass quality (Chicco et al. 1972; Müller et al. 1972; Hew and Hutagalung 1976), except for a firmer carcass and harder fat (Zoby et al. 1971; Hew and Hutagalung 1976). The iodine number of the leaf fat in our studies agreed with values obtained by these other workers.

There were no clinical symptoms of cyanide toxicity in the pigs; however, with such a low level of methionine, subclinical toxicity may occur and, as indicated by Maner and Gomez (1973), could be detected by increased urinary thiocyanate excretion. The cyanide detoxication product was not analyzed in these studies.

Several workers have demonstrated that pigs fed a cassava-based diet grow at a slower rate and less efficiently than those in a cereal control group (Velloso et al. 1967; Hew and Hutagalung 1976; Kitpanit 1975). However, increasing evidence suggests that cassava-based diets, once properly prepared and fed in the proper form, could be totally substituted for cereals in swine rations without detrimental effects on either growth performance or carcass quality. This has been confirmed in the present studies with an even lower quality product. The growing-finishing pigs on cassava-based diets performed as well as those on cereal diets although the crude protein content of the former was at a suboptimum level.

Life-Cycle Swine Feeding Systems with Cassava

Guillermo G. Gómez[1]

Sweet cassava roots are an excellent source of energy for swine feeding if properly supplemented with protein, vitamins, and minerals. Fresh bitter cassava roots because of their high linamarin content are not readily consumed by pigs. Chopped fresh cassava can be fed to pigs throughout their life cycle, separately or mixed with a protein supplement. A tendency to overconsume the protein supplement and therefore to waste the excess protein was observed in all experiments where fresh cassava and supplement were fed ad libitum and separately.

A life-cycle swine feeding program based on the use of high levels of cassava meal (60–70%) was tested at CIAT and compared with a conventional common maize feeding program. Soybean meal was the protein source used for all diets. Gilts in the cassava meal feeding program grew more slowly during pregestation and gestation, as compared with the gilts in the control program. However, gilts fed the cassava diets gained weight during lactation; whereas, the gilts from the maize feeding program lost weight during the same period.

Litter performance at weaning was significantly inferior for the gilts fed the cassava meal diets, and since feed consumption was similar for both experimental groups, the amount of diet required to produce a weaned pig in the cassava feeding program was significantly higher than in the common maize feeding program. Recent experimental information suggests that methionine supplementation is not the factor responsible for the lower reproductive performance obtained in the cassava meal feeding program.

Although most cassava roots are presently used as human food, the prospects for using cassava as an animal feed have been stimulated by the agricultural policy changes of the European Economic Community (EEC), which made the replacement of high-priced cereals in composite feeds by alternative energy feedstuffs, such as cassava, feasible (Coursey and Halliday 1974; Phillips 1974).

As a result of active research on genetic selection and the development of more efficient cultivation methods and production practices, the improvement of cassava yields can be obtained under practical field conditions (CIAT 1975, 1976). Alternative uses of cassava for the industrial starch and animal feed markets thus become economically feasible.

Extensive experimental evidence has been obtained on the use of cassava roots as an animal feed, and least-cost feed rations with varying prices of cassava and other feed ingredients have been estimated for different animal species by several EEC importers of cassava (Phillips 1974). Most of the experimental data on swine feeding have been obtained with growing-finishing pigs, from weaning to marketing weights, but limited information is available on the reproductive periods and life-cycle swine feeding systems. This paper reviews experimental information regarding the use of cassava roots, especially in the form of fresh cassava and cassava meal or flour, throughout the life cycle of the pigs.

Effect of Cyanogenic Glucosides

Cassava varieties are normally classified as sweet or bitter according to their cyanide content. Most of the hydrocyanic acid (HCN) or cyanide (CN) is found in the form of a cyanogenic glucoside known as linamarin. The concentration of linamarin, as evidenced by the cyanide liberated, is substantially higher in the peel of the roots than in the pulp (de Bruijn 1973; Wood 1965). Linamarin releases HCN on treatment with dilute acids; however, the release of HCN is due to the action of the enzyme linamarase, usually present in the tissues (notably the peel) of the roots. Contact of the enzyme with the substrate linamarin normally occurs when the cellular structure of the plant tissues is destroyed.

Pigs do not readily consume fresh bitter cassava roots, and therefore, their growth is retarded. When a protein supplement was supplied ad libitum along with chopped, fresh bitter cassava roots, the pigs consumed an excess of the supplement to compensate for their limited consumption of bitter cassava roots. On the other hand, fresh sweet cassava roots are readily consumed by growing pigs

[1]Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

Table 1. Comparison of intake and performance of finishing pigs fed either sweet or bitter fresh cassava and a protein supplement (P.S.) free choice or controlled (Gomez et al. 1976).

	Sweet cassava +		Bitter cassava +	
	P.S. Ad. lib.	P.S. controlled	P.S. Ad. lib.	P.S. controlled
Avg. daily gain (kg)	0.66	0.77	0.56	−0.08
Daily intake cassava (kg)	2.99	3.40	0.99	0.93
Daily protein intake (kg)	0.81	0.82	1.21	0.22
Total feed intake (kg)[1]	1.98	2.01	1.60	0.58
Feed/gain	2.99	2.61	2.86	Neg.
Protein in diet (%)	14.1	13.3	23.5	13.3

[1] 10% moisture.

and their growth is acceptable, whether the cassava is separately or thoroughly mixed with a protein supplement (Table 1).

Because of the physical contact of linamarase and linamarin when cassava roots are chopped to be dried, most of the HCN is released; thus meal prepared from bitter cassava roots has a relatively low HCN content (100–150 ppm on a dry matter basis). A composite diet including high levels (approx. 73%) of bitter cassava meal (150–200 mg HCN/kg fresh cassava) was consumed slightly less (1.35 kg/day) by growing pigs than a diet based on similar levels of sweet cassava meal (1.77 kg/day) (Gómez et al. 1976), but the difference in consumption was not as great as that observed with the fresh roots. These data suggest that drying the roots greatly reduces the problem of limited consumption of fresh bitter roots by the growing pigs.

Limited information is available on the effect of cyanogenic glucosides present in bitter cassava varieties when fed during the reproductive periods. Fresh sweet cassava plus a 40% protein supplement containing 0, 250, and 500 ppm of added cyanide (as potassium cyanide) throughout the gestation period had no deleterious effect on the reproductive performance of gestating gilts at farrowing; nor was any carry-over effect observed in the subsequent lactation performance (Tewe 1975). During lactation all gilts were fed a control diet based on common maize and soybean meal. An enlargement of the thyroid glands was observed in fetuses at the end of gestation of gilts fed diets containing high cyanide levels (Tewe 1975); however, those gilts that received high levels of cyanide during the gestation period performed similarly at weaning time. Apparently the placental barrier plays a significant role in protecting the growing fetuses from toxic effects. Experimental information (Ekpechi 1967, 1973; Ermans et al. 1969; van der Velden et al. 1973) has been published in which a goitrogenic character is attributed to cassava, especially in areas where dietary iodine is limited. A working hypothesis has been proposed (Ermans et al. 1973) to explain the goitrogenic characteristic of cassava, as a consequence of the increased thiocyanate concentration in the blood. Fortunately, most of the cassava cultivars grown in Latin America are sweet, therefore no major problems are encountered in feeding fresh, ensiled, or dried cassava.

Sweet Cassava Roots for Swine Feeding

Fresh roots and meal are the forms in which cassava is most commonly used for swine feeding. Ensiled roots are also acceptable to pigs, and could be a form of preservation in highly humid environments such as the lowland tropics. Information on the use of fresh cassava in the different periods of the life cycle of the pig has been obtained through collaborative research between the Centro Internacional de Agricultura Tropical (CIAT) and the Instituto Colombiano Agropecuario (ICA) in Colombia.

Fresh cassava was fed ad libitum, either separately from the protein supplement or thoroughly mixed with it, and fed in quantities calculated to supply the minimal daily requirements of the growing pigs. The control diet was fed in automatic feeders, and all experimental animals were kept in confinement on cement-floored corrals. Body weight gain was similar for the animals fed the control diet (0.84 kg/day) and those fed fresh cassava

Table 2. Performance of growing-finishing pigs[1] fed fresh sweet cassava and a 20, 30, or 40% protein supplement (P.S.) free choice (Job 1975).

	Control diet	Cassava +		
		20% P.S.	30% P.S.	40% P.S.
Daily gain (kg)	0.63	0.70	0.67	0.65
Daily feed intake (kg)				
Fresh cassava	—	1.78	2.74	3.32
Protein supplement	—	1.39	1.00	0.75
Total feed intake[2]	2.08	2.08	2.07	2.04
Feed/gain	3.30	2.97	3.09	3.14
Protein in diet (%)	14.3	14.6	16.6	17.3

[1]Mean of five individually fed pigs per treatment: avg. initial weight 21.1 kg; avg. final weight 86.1 kg; 98-day trial.
[2]Approximately 10% moisture content.

roots and the protein supplement ad libitum (0.83 kg/day). The animals fed fresh cassava mixed with controlled quantities of the protein supplement, consumed less cassava and protein supplement; consequently, the average daily gain was lower (0.79 kg/day) than that of the other two experimental groups. On the other hand, the effect of restricting both cassava and the protein supplement according to the appetite and needs of the animals resulted in a better feed efficiency for the cassava plus protein mixture (2.90 kg feed/kg body wt compared with 3.43 for the control diet and 3.36 for the cassava plus the protein supplement).

The amount of fresh cassava required per animal to reach marketing weight (95–100 kg) was approximately 390–400 kg of fresh chopped roots. The basic difference in feed intake was the amount of protein supplement saved when it was mixed with chopped fresh cassava; however, the extra labour required for mixing could reduce the advantages of this method. The consumption of fresh cassava by growing-finishing pigs varies according to the protein content of the supplement. The daily intake of cassava was greater when the protein supplement (fed free choice) supplied higher protein levels and the intake of the supplement decreased. An overall tendency to overconsume protein throughout the growing-finishing periods was observed as the protein content of the supplement increased (Table 2).

Fresh sweet cassava is readily consumed by gestating gilts or sows when an adequate supplement provides a good source of protein, minerals, and vitamins. The results of an experiment to evaluate the use of fresh cassava by gestating gilts are shown in Table 3. All gilts were fed a control diet (maize-soybean meal) throughout the lactation period. Gestating gilts fed fresh cassava and kept in confinement gained more body weight during gestation than both those fed fresh cassava but kept on pasture lots, and those gilts fed the control diet. The number of baby pigs farrowed and weaned by the gilts fed cassava in confinement was, however, less than that of the other two experimental groups.

Lactating sows fed a diet based on fresh chopped cassava mixed with a 40% protein supplement consumed on the average 6.5 kg of fresh cassava and 1.2 kg of protein supplement per day. The litter performance for the cassava-fed sows was inferior with respect to the number of weaned pigs (7.6/litter) to the control-fed sows (9.0/litter); the average weight of weaned pigs was higher (7.63 vs. 6.03 kg) for the cassava-fed sows, but total litter weight was similar for both experimental groups (54.3 kg for the control vs. 58.0 kg for the cassava-fed group).

Results obtained during the different periods of the swine life cycle suggest that fresh cassava roots are an excellent source of energy for growing-finishing pigs when properly supplemented with protein, minerals, and vitamins. Handling of feeding programs based on fresh cassava is an important aspect to be considered. Self-feeding systems, based on the separated ad libitum consumption of fresh chopped cassava roots and protein supplement, lead to an excess intake of the supplement and result in a daily protein uptake significantly higher than the recommended level. A controlled supply of chopped cassava mixed with a protein supplement restricts excess protein consumption to normal levels, but the additional labour must be taken into account.

Table 3. Performance of gestating sows fed diet based on fresh cassava and a protein supplement (P.S.) (40%).

	Control diet[1]	Fresh cassava + P.S.	
		Pasture[2]	Confinement[3]
No. bred	10	10	10
No. farrowed	9	7	7
Weight (kg)			
Breeding	165.8	163.6	152.8
Farrowing	185.7	188.5	190.5
Gestation wt. gain	19.9	24.9	37.7
Lactation wt. gain	13.2	7.7	8.4
Progeny at farrowing			
No. pigs/litter	10.4	10.0	7.7
Litter wt. (kg)	13.3	11.2	9.1
Individual wt. (kg)	1.28	1.12	1.18
Progeny at weaning (35 days)			
No. pigs/litter	8.3	7.3	6.9
Individual wt. (kg)	6.94	6.05	6.49

[1] 1 kg/sow/day.
[2] 1.7 kg fresh cassava + 0.4 kg P.S./sow/day.
[3] 3.1 kg fresh cassava + 0.62 kg P.S./sow/day.

During the reproductive periods of gestation and lactation, a controlled individual feeding system is the most advisable under all circumstances. Unfortunately there is no information available on the use of fresh cassava during the consecutive gestation and lactation periods. It is assumed that no major differences would be encountered if a feeding system was based on the continuous use of fresh cassava; however, more experimental information is needed, especially with regard to the lactation period.

Life-Cycle Feeding Using Sweet Cassava Meal

Because of the handling difficulties normally encountered when fresh cassava roots are used for swine feeding, the most convenient and practical way to handle cassava is to dry the chopped fresh roots and grind them into a meal or flour, which can be easily incorporated and mixed into composite diets. Cassava meal is an excellent energy source of good nutritive value due to its highly digestible carbohydrates (70–75%), mainly starch, but its protein content is extremely low, therefore it requires supplementary protein to balance the diet. In all experimental work at CIAT, cassava meal has been obtained from sweet cassava cultivars, mostly of the variety Llanera. The roots are chopped, sun dried on cement floors, and then ground into a meal.

A life-cycle swine feeding program was outlined, in which the level of crude protein in the experimental diets followed the recommendations of the National Research Council (1973) (i.e. growing (20–50 kg) 16%; finishing (50–90 kg) 13%; pregestation (90–120 kg) 13%; gestation 16%; lactation 16%; and baby pigs (starter feed, 10–56 days) 18%). The feeding program was based on cassava meal and was simultaneously compared with a control feeding program based on common maize. For both programs, soybean meal was used as the protein source to balance the experimental diets (Gómez et al. 1977). The experimental work studied the long-term effects of feeding high levels of cassava meal on the reproductive performance of gilts.

Experimental animals were grouped according to their initial body weight and litter history into two groups of 16 weaned female pigs each. Selected gilts initiated the feeding program, either on cassava meal or common maize, when they weighed approximately 20 kg. They were fed the experimental diets throughout their growing (20–50 kg), finishing (50–90 kg), pregestation (90–120 kg), gestation, and lactation periods. Methionine was not added to any of the experimental diets (composition of the diets is given by Gómez et al. 1977). Boars used to breed the experimental

Table 4. Experimental results of the gestation and lactation periods in life-cycle swine feeding program based on cassava meal or common maize.

	Common maize	Cassava meal
No. gilts farrowed	10	14
Changes in gilt weight (kg)		
Weight at breeding	127.6	118.5
Weight at 110 days gestation	175.6	156.0
Total gestation gain	48.3	37.5
Postfarrowing wt.	160.6	146.1
Net gestation gain	33.1	27.6
Weaning wt.	153.9	159.6
Change during lactation	−6.7	+13.5
Change during gestation-lactation	+26.3	+41.1
Data at farrowing		
No. live-born pigs	10.0	8.4
Avg. weight/pig (kg)	1.09	0.97
Data at weaning (56 days)		
No. weaned pigs	9.4	6.6
Avg. weight/pig (kg)	15.87	15.70
Total litter wt. (kg)	145.4	103.6

gilts were fed a standard common maize-soybean meal diet. Experimental diets were supplied in automatic feeders during the growing, finishing, and lactation periods. Individual, daily controlled feeding was undertaken during the pregestation (2.0 kg/diet/gilt) and gestation (1.8 kg/diet/gilt) periods. In all phases or periods of the experiment, water was available to the animals at all times.

Results obtained during the growing-finishing periods were: average daily gain (kg) 0.77 and 0.71; average daily feed intake (kg) 2.38 and 2.30; and feed/gain 3.09 and 3.24, for the maize and cassava meal diets, respectively. The average daily gain obtained by the growing gilts fed the cassava meal-based diet was significantly lower ($p < 0.05$) than that of the gilts fed the control diet but similar to gains previously reported when fresh cassava or cassava meal-based diets were fed to groups of females and castrated males (Maner 1972). Reproductive performance of the two experimental groups is summarized in Table 4. In general, gilts in the cassava meal feeding program gained less body weight (37.5 vs. 48.3 kg) during gestation than gilts in the common maize feeding program; however, gilts on cassava meal diets continued gaining body weight (+13.5 kg) throughout their lactation period; whereas, the gilts on common maize diets lost weight (−6.7 kg) during the same period. Consequently the overall change in body weight of the gilts in the cassava meal feeding program was significantly higher ($p < 0.05$) than that of the gilts in the common maize feeding program (41.1 vs. 26.3 kg, respectively). The number and weight of the live-born baby pigs were similar ($p > 0.05$) for both experimental groups, although a trend of fewer and lighter baby pigs per litter was observed for the gilts in the cassava meal feeding program. At 21 days of age and thereafter, the number of suckling pigs per litter was significantly inferior ($p < 0.05$), by approximately three pigs per litter, for the lactating gilts in the cassava feeding program. The average body growth of the suckling pigs in both experimental groups was similar, as evidenced by practically the same average weight at weaning time (15.87 vs. 15.70 kg). However, because of the larger number of weaned pigs per litter, the common maize feeding program produced heavier litters than the cassava meal feeding program (145.4 vs. 103.6 kg). A similar trend of raising fewer suckling pigs throughout the lactation period was previously reported in feeding fresh cassava or cassava meal during either the gestation or lactation periods (Maner 1972).

The reasons or factors involved in the lower reproductive performance of the gilts in the cassava meal feeding program are not clear. The slightly lower body weight, although within the normal range, of the gilts fed the cassava meal-based diet at breeding could have had an adverse effect on the number of embryos, which would subsequently affect the number of live-born pigs. From the production point of view, however, the most striking difference was the significantly lower number of weaned pigs in the cassava feeding program. Whether these results are a consequence of a carry-over effect from the gestation period or are due to the gain in body weight during lactation (or to both) needs further experimental evidence.

The absence of methionine supplementation does not appear to be responsible for the lower reproductive performance of gilts in the cassava meal feeding program. The results of recent experimental work in which cassava meal-soybean meal based diets were fed throughout the gestation and lactation periods, with and without methionine, showed that gilts fed the cassava meal diets performed simi-

Table 5. Effect of methionine supplementation in cassava meal-based diets for gestating-lactating gilts.

	Common maize	Cassava meal + soybean meal	
		0.0% methionine	0.3% methionine
No. gilts farrowed	14	10	10
Body weight of gilts (kg)			
At breeding	117.0	121.2	120.1
Total gain, gestation	56.9	49.1	47.6
Weight loss, lactation	17.3	13.8	15.3
Total gain, gestation-lactation	39.6	35.3	32.3
Data at farrowing			
No. pigs/litter	8.5	9.1	9.4
Avg. pig wt. (kg)	1.09	1.06	1.07
Data at weaning (56 days)			
No. pigs/litter	7.1	8.2	8.0
Avg. pig wt. (kg)	16.74	16.15	16.54
Total litter wt. (kg)	117.02	128.50	131.95

Table 6. Intake (kg) of experimental diets and basic ingredients in life-cycle swine feeding programs based on cassava meal or common maize.

	Common maize diets			Cassava meal diets		
	Total	Maize	Soybean meal	Total	Cassava meal	Soybean meal
Growing	77.9	59.5	14.7	91.9	63.6	23.9
Finishing	137.9	121.2	10.1	124.0	94.1	23.9
Pregestation	230.6	202.7	16.8	217.2	164.9	41.9
Gestation	209.9	160.4	39.5	211.0	146.0	54.9
Lactation	265.5	202.8	49.9	292.5	196.0	82.8
Baby pig/starter	79.6	49.8	18.1	51.1	25.9	17.7

larly, irrespective of the methionine supplementation, at least for the first gestation and lactation periods (Table 5). The experimental period was initiated at breeding when gilts exhibited similar body weights, and individual controlled feeding (1.8 kg diet/gilt/day) was followed throughout the gestation period. On average, all animals of the experimental groups lost weight during lactation, as compared to the weight gain exhibited during lactation in the previous experiments (Gómez et al. 1977).

The use of methionine supplementation is recommended when high levels of cassava are mixed in composite diets with plant protein sources, such as soybean meal. Apparently, methionine supplementation serves the double purpose of improving the protein quality of the diets and of supplying a readily available source of labile sulfur for cyanide detoxication (Maner and Gómez 1973). In the case of experimental information obtained with rats, methionine supplementation in cassava meal diets normally produces significant improvement because the protein source used is casein, which is known to be deficient in this amino acid. In addition, for this type of biological evaluation with laboratory animals, suboptimal levels of dietary protein are commonly employed, making a response to methionine supplementation feasible. The effect of methionine supplementation would depend basically on the protein quality of the feedstuff used as the protein source.

Data on intake of the experimental diets and the basic ingredients recorded from the life-cycle swine feeding program based on cassava meal are presented in Table 6. Overall total intake of experimental diets and for individual periods were similar for both groups. The most important difference was the amount of soybean meal required for the cassava meal feeding program as compared with the maize-based

feeding program. Considering only the growing and finishing periods, the total relative amounts of cassava meal and soybean meal required per animal to reach marketing weight are 87 and 193%, respectively, of the amounts of common maize and soybean meal required to obtain similar performance with pigs in the common maize feeding program. Almost twice as much soybean meal is required for the growing-finishing periods of feeding programs based on cassava.

Feed intake during the reproductive periods (pregestation, gestation, and lactation, as well as the baby pig starter feeding) was also similar for both feeding programs. The cassava meal-based feeding program required 87 and 159% of cassava meal and soybean meal, respectively, as compared with the amounts of common maize and soybean meal required in the feeding program based on common maize. However, because of the lower experimental results obtained at weaning time with the cassava meal-based feeding program, the amount of diet required to produce a weaned pig was 45% higher (119.0 vs. 82.1 kg diet/weaned pig) for this feeding system as compared with the common maize feeding system. These data support the theoretical concept that the economic feasibility of using cassava as a substitute for other energy sources would depend on the relative price of cassava, as well as the price of the protein supplement needed to balance a cassava-based diet (Phillips 1974).

Cassava as a Substrate for Single-Cell Protein Production: Microbiological Aspects

Kenneth F. Gregory[1]

Data from several laboratories have shown that filamentous fungi produced on cassava and other substrates are satisfactory as high-protein animal feed. At Guelph, simple low-cost methods for converting cassava to microbial protein were sought. Silage was produced, from cassava and inorganic nitrogen, with up to 6.4% protein but no practical way could be devised for doing this in rural, tropical areas. Liquid, aerated fermentation with thermotolerant fungi was shown to hold more promise of having practical value. Whole ground cassava can be used in a nonaseptic system because the fermentation's high temperature (45–47 °C) and low pH (3.5) inhibit contaminants. Water at ambient temperature suffices to remove excess heat. The fungi hydrolyze the starch by their own enzymes and can be harvested by simple filtration. The three cultures that gave the best nutritional response with rats contained 44–50% crude protein and 35–38% true protein. The product formed with *Aspergillus fumigatus* I-21A on whole cassava (including nonfermented fibre and bark) contained 37% crude and 27% true protein. Simple conditions for a daily batch production schedule have been defined. Fungi capable of growth at body temperature could be an infection biohazard for unusually susceptible individuals. A nonrevertible, asporogenous mutant of *A. fumigatus* I-21 (I-21A), used to avoid risk of infection by spore inhalation, may not be a sufficient safeguard since viable hyphal fragments can occur in an aerosol. "Cold-sensitive" mutants unable to grow below 40 °C, but able to grow normally at 45–47 °C, were isolated by five sequential mutations. Nonrevertible mutants, required for absolute safety, have not yet been obtained.

Cassava (*Manihot esculenta*) is believed to be one of the most efficient converters of solar energy to carbohydrate, with an ability to store energy at a daily rate per hectare appreciably greater than that of other high-yielding crops such as maize and rice (Coursey and Haynes 1970). The storage roots are as poor in protein, however, as they are rich in calories. The crude protein content (total N × 6.25) of whole cassava roots averages 3.5%, or less, of their dry weight (Pond and Maner 1974; Oke 1966; Jennings 1970; Grace 1971). Furthermore, 40–60% of the total nitrogen is nonprotein nitrogen (Pond and Maner 1974). It follows that, when cassava is used as an animal feed, large amounts of protein-rich feeds must be employed to balance the ration.

Microbial Protein from Cassava

Several investigators have studied the use of microorganisms to convert cassava into microbial protein. The traditional fermentation of grated cassava, developed by the Amerindians and used for making farinha do mandioca in Brazil and the similar product gari in Africa, cannot result in much net protein synthesis because supplemental nitrogen is not added to the mash. The consecutive growth of the bacterium *Corynebacterium manihot* and the yeast *Geotrichum candida*, which occurs during the fermentation (Collard and Levi 1959; Akinrele 1964), might convert some of the nonprotein nitrogen into protein but no data are available on this point. A solid-type fermentation process for cassava, modeled on traditional food processes in Southern Asia, especially the tempeh produced in Indonesia, was developed at the Tropical Products Institute in London (Brook et al. 1969; Stanton and Wallbridge 1969, 1972). In this process the roots were peeled, dried, and ground to a flour. The fungus inoculum was added as spores along with ammonium nitrate, monopotassium phosphate, and water. The paste-like mixture was extruded into spaghetti-like strands and allowed to ferment in shallow trays for 3 days. Species in several genera of fungi were used but *Rhizopus* species appeared to be preferred. Final yields of crude protein ranging from about 2 to 4% were reported. Because the peeled cassava roots contained only about 0.2% protein, the percentage increase in protein was impressive. The final product must be considered still to be a low-protein food, however, and the process, as described, appears to be unsuitable for the production of animal feed.

Varghese et al. (1977) described a procedure

[1]Department of Microbiology, College of Biological Sciences, University of Guelph, Guelph, Canada N1G 2W1.

in which cassava chips, supplemented with chicken dung, were steamed, inoculated with *Aspergillus* or *Rhizopus* cultures and incubated in fermentation trays. The final products contained about 4–10% crude protein but the data presented do not permit discrimination between fungal protein and nonconverted nitrogenous compounds added with the dung. A similar procedure followed by Hutagalung and Tan (1977) yielded a product from cassava, dung, and a *Rhizopus* sp., with 10% "true protein," about one-third of which can be accounted for by the true protein contributed directly by the dung and the cassava.

Much higher yields of protein have been achieved in liquid fermentation systems based on cassava. Stasser et al. (1970) described a process in which the yeast *Candida utilis* was used to produce a product containing 35% crude protein on a dry weight basis. Most yeasts are unable to hydrolyze starch, therefore the process required enzymatic or acid hydrolysis of the cassava starch, as well as sterilization of the substrate, aseptic conditions, and centrifugation to recover the product.

Simpler processes are possible with filamentous fungi, which can hydrolyze starch with their own amylases and can be recovered by filtration rather than centrifugation. Gray and Abou-El-Seoud (1966) grew several filamentous fungi on ground cassava roots supplemented with ammonium chloride and corn steep liquor. Products containing 13–24% crude protein were obtained. Brook et al. (1969) obtained similar concentrations of protein with cassava fermentations using 27 strains of fungi but one culture yielded mycelium with 33.6% crude protein. The best-yielding fungi studied in our laboratory produced mycelium with 44–50% crude protein.

Value of Fungi as Animal Feed

Extensive studies have been carried out on the conversion of other substrates to protein by means of filamentous fungi. Some of these are listed in Table 1. The first four processes cited have shown particular promise. The process described by Church et al. (1972) was primarily designed to reduce the biochemical oxygen demand of corn and soybean processing wastes by converting the organic matter into mycelium. Nonaseptic continuous fermentation was carried out at the 40 000 litre scale in open oxidation ditches and resulted in a high-protein product that was readily consumed by rats and produced good growth responses. Tate and Lyle Limited have operated a pilot plant on Cyprus at the 3000 litre scale in which *Aspergillus niger* was produced from the carob bean (Imrie and Vlitos 1975). The product was readily accepted by both rats and boiler chicks with excellent results. More recently, a *Fusarium* species, which has a higher crude protein content (41–51%), has been under investigation in their laboratories. The strain of *Fusarium graminearum* studied by Anderson et al. (1975) is notable for its high crude protein content (54%). The "Pekilo" process developed at the Finnish Pulp and Paper Research Institute was successfully operated, with a 15 m^3 fermentor, on a continuous basis, producing mycelium of a strain of the fungus *Paecilomyces varioti* from sulfite waste liquor (Romantschuk 1975). The process was run aseptically. A prototype Pekilo-plant has since reached normal commercial operation (M. Ingman, personal communication) and the product has been approved as an animal feedstuff by the Finnish authorities. Feeding experiments with pigs, chicks, and calves showed that the fungal protein gave growth responses equivalent to those obtained with skim milk powder.

The above studies, as well as those carried out in our own laboratories (Khor et al. 1976), have clearly shown that fungal mycelium can serve as a satisfactory protein-rich animal feed. Smith et al. (1975), however, found that a strain of *Aspergillus oryzae* that gave good results with rats gave poorer results than expected with pigs. The nutritional value of fungal mycelium tested at Guelph is discussed by Alexander (1977).

Increasing the Protein Content of Cassava Silage by Fermentation

Studies were undertaken in our laboratories on the microbial enrichment of cassava by two distinct types of processes — a moist solids fermentation and a liquid aerated fermentation. The first approach is described in this section.

The studies of Tutarov et al. (1967) with N-supplemented maize silage and Brook et al. (1969) with cassava-based "vegetable-cheeses" suggested that a significant increase in the protein content of cassava silage might be possible by encouraging microbial growth in N-supplemented cassava silage. Because the production of cassava silage has value in itself, as

Table 1. Some filamentous fungi used for protein.

	Substrate	Protein in mycelium: % of dry wt.	Method of assay	Reference
Trichoderma viride	corn and soybean processing wastes	42–45	sum of amino acids	Church et al. 1972
Aspergillus niger	carob extract	35	Lowry method	Imrie & Vlitos 1975
Fusarium graminearum	starch	54 42	total-N × 6.25 amino-N × 6.25	Anderson et al. 1975
Paecilomyces varioti	spent sulfite liquor (pulp mill)	55–60	Not reported	Romantschuk 1975
Aspergillus oryzae	barley grain	44	total N × 6.25	Reade & Smith 1975 Smith et al. 1975
Sporotrichum pulverulentum	agricultural wastes	25–40	sum of amino acids	Von Hofsten 1976 Von Hofsten & Ryden 1975
Aspergillus fumigatus	cellulose	13.3	sum of amino acids	Rogers et al. 1972
Heterocephalum aurantiacum	cassava	33.6	total N × 6.25	Brook et al. 1969
Aspergillus fumigatus	cassava extract	44 35	total-N × 6.25 amino-N × 6.25	Gregory et al. 1976b

Table 2. Protein enrichment of cassava during experimental ensiling procedures.

Treatment of ground cassava[1]	Inoculation with *R. oligosporus* M87	Percentage protein[2]: 0 °C incubation	37 °C incubation	Final pH at 37 °C[3]
None	−	1.09	1.08	3.85
None	+	1.20	1.01	3.85
Supplement[4]	+	0.82	0.76	3.25
Supplement + ethylene oxide sterilization	+	0.88	3.13	—
Supplement + heat sterilization	+	1.03	3.65	3.45
Supplement + continuous perfusion	−	0.58	3.22	7.80
Supplement + continuous perfusion	+	0.63	3.17	7.75
Supplement, thin layers, eluates recycled discontinuously	+	0.76	6.44	—

[1]All samples were incubated in a laboratory-scale silo except in the last two experiments, where recycling perfusion units and large Buchner funnels were used. Incubation times ranged from 8 to 14 days.
[2]Protein = nitrogen not extractable with 5% trichloroacetic acid at 4 °C, times 6.25.
[3]Initial pH of the ground cassava ranged from 6.25 to 6.50.
[4]Supplement consisted of mineral salts and NH_4NO_3.

a means of preserving cassava as feed, even a modest increase in its protein content could have considerable value. This possibility was investigated by Sprung and Smith (see Sprung 1974). The results of this study are summarized in Table 2.

Cassava silage was readily produced in laboratory-scale fermentors and achieved satis-

factory acidity levels of pH 3.8 or less after six or more days incubation at 37 °C. The protein level of the cassava (calculated on the basis of nitrogen not extracted by cold trichloroacetic acid) was slightly over 1% on a dry weight basis and did not change significantly during the ensiling process (first line in Table 2).

A total of 171 new isolates and known cultures of moulds, yeasts, and bacteria were screened to select those that hydrolyzed starch but not protein, that grew at pH 4 and 45 °C, produced acid, and had a crude protein content of 28% or higher. A strain of *Rhizopus oligosporus* (M87) met all these criteria and grew well at high CO_2 and low O_2 tensions. This culture was used as an inoculum to supplement the normal cassava microflora in most experiments.

As expected, silage made with added *R. oligosporus* but without supplemental nitrogen did not result in increased protein levels although microbial growth was stimulated sufficiently that a lower final pH (3.25) was reached. Unfortunately, the addition of mineral salts and ammonium nitrate to nonsterilized chopped cassava did not result in increased protein in the final silage either. When the cassava was treated with ethylene oxide, to kill the competitive microorganisms, however, the fungus grew well and raised the protein content to over 3%. Heat sterilization of the cassava permitted greater growth and protein production, possibly because it gelatinized the starch and made it more readily attacked by the fungus.

When nonsterilized silage was continuously perfused with water containing the mineral and nitrogen supplement, the protein content was similarly increased to over 3%. The indigenous microflora was as effective in doing this by itself as when it was supplemented with the mould inoculum. It was believed that the low oxygen supply was probably limiting the amount of microbial growth and thus the amount of protein that was synthesized. Indeed, when the cassava was incubated in thin layers and liquid eluates from the cassava were recycled discontinuously, the protein content reached almost 6.5%, but the product was not always satisfactory as silage.

It was concluded that none of the effective methods would be of practical value for rural operations in tropical countries. It was apparent, that the closer the procedure came to an aerated liquid culture system the greater was the protein yield.

Table 3. Isolation of thermotolerant, amylolytic high-protein fungi.

Stage of screening	Number
Soil samples tested	724
Cultures isolated	147
Cultures with >44% crude protein	15
Cultures used in feeding trials	12
Cultures giving PER of 2.3 or higher[1]	3

[1]PER = protein efficiency ratio (g gain/g protein fed) in rat-feeding trials using diets with 10% true protein supplemented with methionine, normalized to a value of 2.5 for casein supplemented with methionine and tryptophan (Khor et al. 1976; Gregory et al. 1977).

Isolation of Cultures for Liquid Fermentation

At the outset, it was decided that the problems encountered in producing low-cost microbial protein from cassava in tropical countries should be minimized by judicious selection of the microorganisms (Table 3). Soil samples from 724 locations in Canada and Colombia were screened for organisms that would grow at a low pH (3.5) and temperatures in excess of 45 °C (Reade and Gregory 1975; Gregory et al. 1977). Only rare thermotolerant fungi could grow under these restrictive conditions and the fermentation could be expected to be immune to bacterial or yeast contamination and relatively resistant to fungal contamination. Furthermore, a high temperature fermentation would avoid the necessity of mechanical refrigeration for cooling, even in tropical countries. Cultures able to grow under these conditions were further screened for amylase activity as well as protein and methionine content. Amylolytic fungi could utilize cassava starch without the need of prior acid or enzymatic hydrolysis. Methionine was given special attention because almost all sources of single-cell protein are deficient in this amino acid.

The twelve cultures best meeting the above requirements were evaluated in rat-feeding experiments (Khor et al. 1976; Gregory et al. 1977; Alexander 1977). The three that gave protein efficiency ratios of 2.3 or higher are listed in Table 4. The first of these to be isolated was *Aspergillus fumigatus* I-21 (ATCC 32722) and it has received the most attention so far. As this species can cause a lung infection called aspergillosis if massive numbers of spores are inhaled by certain susceptible individuals, a nonsporeforming mutant (I-21A, ATCC 32723) was isolated following gamma

Table 4. Some properties of three thermotolerant, amylolytic high-protein fungi.[1]

	Crude protein (% of dry matter)	True protein (% of dry matter)	Doubling time at 45 °C (h)
Aspergillus fumigatus I–21 (parent)	44	35	3.5
A. fumigatus I-21A (asporogenous mutant)	49	37	3.5
Rhizopus chinensis 180	49	37	<3
Cephalosporium eichhorniae 152	50	38	5

[1]Data from Reade and Gregory (1975) and Gregory et al. (1977).

Table 5. Fermentation conditions selected for the nonaseptic production of protein from cassava mash by *A. fumigatus* I-21A.

Condition	Reasons for selection
Carbohydrate concentration = 4% (ca. 15% fresh cassava)	Fermentation is completed in 20 h from a 6.7% inoculum, permitting a daily production schedule. Higher concentrations take longer; lower concentrations give lower yield per litre
Mash heated to 70 °C for 10 min, immediately after grinding, in one-half final volume	Gelatinizes starch permitting complete utilization; prevents development of antifungal activity; provides desired starting temperature after dilution to final volume
Nitrogen source = urea (1.72 g/l)	No automatic pH control required; whereas, $(NH_4)_2SO_4$ results in excess acidity
Mineral supplement = KH_2PO_4 (0.25 g/l)	Assures sufficient phosphorus even with cassava roots which are low in P. All other mineral requirements except S are supplied by the cassava roots
Initial pH adjustment with sulfuric acid	Supplies sulfur requirement as well as acidity
pH 3.5	Optimum for protein production; inhibits bacterial growth
Temperature = 45 °C	Inhibits yeast growth, thus permitting use of nonaseptic conditions (although optimum temperature for the fungus is 37–40 °C)
Vigorous agitation and aeration during growth	Provides rapid oxygen transfer to growing cells

irradiation (Nielsen 1976) and used for most of the subsequent studies. The mutant could not be induced to form spores on a variety of media in a broad range of physical environments, nor could it be induced to back-mutate by either radiation or chemical mutagens. The asporogenous mutant was identical to the parent in its growth characteristics but had a slightly higher protein content (Table 4). The culture giving the best results in feeding trials was *Cephalosporium eichhorniae* 152 but this culture grows more slowly than the others and the establishment of optimum growth conditions to permit reproducibly high yields is proving to be difficult.

Fermentation Conditions for *A. fumigatus* I-21A

The conditions established for the production of microbial protein from cassava by *A. fumigatus* I-21A are summarized in Table 5. A self-aspirating fermentor was specifically designed for this process (Azi et al. 1975; Meiering and Azi 1977) and models with 200 and 3000 litre capacities were constructed for use in a pilot plant operation. The 6.7% inoculum provided by the 200 litre fermentor permits concentrations of cassava carbohydrate up to 4% to be converted to mycelium in 20 h, thus allowing 4 h for harvesting and refilling the fermentor on a daily production schedule.

The highest concentrations of protein in the product were obtained when the cassava roots were peeled prior to being ground. The peeling step was found to be unnecessary, however, because the fungus grew equally well when the whole roots were used and the final yield of protein per gram of carbohydrate supplied was the same (Reade and Gregory 1975). The protein concentration in the final product was lower, however, because of the presence of unfermented cassava fibre and bark.

Heating of the cassava mash to about 70 °C, in about one-half the final volume of water, was found to be necessary for three reasons. Firstly, unless the starch was gelatinized by heat it was not attacked rapidly or completely by the organism. Secondly, initial heating was required because of the high fermentation temperature used. Excess heat input was avoided if the volume heated was adjusted so that the subsequent addition of water at ambient temperature brought the mash to the fermentation temperature of 45–47 °C. Subsequent heat input was not required because the growing culture generated sufficient heat. Thirdly, if not heated, the cassava mash developed fungistatic activity that caused an unacceptably long lag in growth of the culture. The fungistatic activity is presumed to be due to the release of hydrogen cyanide from the glucoside linamarin when the grinding process brings this glucoside and the enzyme linamarase together (de Bruijn 1973). Dumping the ground cassava into hot water immediately after grinding prevented the development of most of this fungistatic activity, presumably because of the inactivation of the enzyme (Reade and Gregory 1975).

An alternative approach to decreasing the growth lag when an inoculum is placed in fresh cassava medium, is the isolation of cyanide-resistant mutants. Nielsen (1976) isolated mutants from gamma irradiated spores of *A. fumigatus* I-21 that had more than a threefold increase in tolerance to potassium cyanide as determined by respiration measurements with a Clark-type oxygen electrode. Although the cyanide-resistant mutants of microorganisms that have been described previously had respiratory impairment and grew slowly, the mutants isolated in this study had growth rates identical to that of the parent. Such cyanide-resistance has not yet been coupled with a mutation for asporogeny or a "safe" mutant culture (see Safety Considerations).

The only supplemental nutrients required for the fermentation are sulfuric acid (which lowers the initial pH to 3.5 and provides sulfur), KH_2PO_4 (which is only required in small amounts because the cassava roots supply all the necessary potassium and almost enough phosphorus), and urea (as the nitrogen source). All of the other mineral requirements are present in excess amounts in cassava roots (Gregory et al. 1976a). When urea is used as a nitrogen source no automatic pH control is required. Indeed, the only automatic control system required is a cooling system whereby water at ambient temperature is passed through a heat-exchanger in the fermentor as required to keep the temperature down to 45–47 °C.

At the completion of the fermentation only about 5% of the initial carbohydrate remained unutilized when finely ground cassava was used (Reade and Gregory 1975). When a rasper was used to prepare the cassava mash, however, a larger residue of carbohydrate remained (Santos and Gomez 1977) presumably because of poorer access of the fungus to its substrate. The fibrous nature of the final mycelial product was found to be well-suited to recovery by filtration. A simple roller-press filter system has been designed for this process (Meiering and Hayes, unpublished).

The final yield of product from whole cassava was about 520 g/kg carbohydrate supplied. The product contained 37% crude protein and 27% true protein. The concentration of protein in the product is appreciably less than in the mycelium itself, because of the presence of nonfermented cassava fibre and bark.

Safety Considerations

Two aspects of safety need to be considered in the production of single-cell protein (SCP). One is the freedom from toxic effects of the product for the consumer, whether that be man or animal. The cultures studied in this project appear to be harmless as far as rats are concerned (Khor et al. 1975; Alexander 1977) but toxicological evaluation of their effects on livestock needs to be done.

The other safety aspect is the possibility of infection or allergy in the personnel involved in producing the SCP. Many fungi that are capable of growing at body temperature are "opportunistic pathogens" in that they may incite infections in individuals who already have certain predisposing diseases, such as

tuberculosis, or are undergoing treatment with immunosuppressive drugs such as corticosteroids (Emmons et al. 1970; Chick et al. 1975). The genera most often involved are *Aspergillus* (causing aspergillosis) and *Rhizopus* and *Mucor* (causing phycomycoses).

Among the three species we have been studying that gave the best nutritional responses in rats, many strains of *Aspergillus fumigatus* are known to be involved in aspergillosis. Thus strain I-21 should be treated as if it has this potential. The other two species do not appear to have been reported as causes of infection in man. Nevertheless, other thermotolerant species of *Rhizopus* have been thus incriminated, and when *Rhizopus* infections have occurred they have often been fulminating infections and rapidly fatal (Emmons et al. 1970). Under normal circumstances, *R. chinensis* is probably not encountered in high concentrations so that we cannot be sure that *R. chinensis* 180 might not be hazardous for rare individuals if massive exposure occurs. *Cephalosporium eichhorniae* 152 is acidophilic and grows little or not at all above pH 5 in most media. Although slow growth can occur at higher pH levels in rich media, this pH sensitivity, together with the absence of reports of pathogenicity for this species, give reasonable assurance of safety with this culture.

Use of the asporogenous mutant *A. fumigatus* I-21A entirely avoids the risk of spore inhalation, which is probably the only way aspergillosis arises in nature. Our recent experience with pilot-plant scale equipment, however, has shown that viable mycelial fragments may become airborne in the form of an aerosol. Aerosol formation is particularly prone to occur during the harvesting procedure when large volumes of liquid, containing hyphal fragments, are being separated from the bulk of the biomass. Recent experimental studies on aspergillosis (Sidransky 1975) have indicated that an animal's resistance to infection with germinated spores (and presumably hyphal fragments) may be much less than to spores. These considerations have led us to believe that the use of an asporogenous mutant is not a sufficient safeguard.

Ultimate safety would be achieved if a non-revertible mutant could be isolated that was unable to grow in the conditions found in the body. A major step in that direction has been achieved by the isolation of mutants of *A. fumigatus* I-21 that are unable to grow at temperatures below 40 °C but are able to grow normally at the fermentation temperature of 45–47 °C (Nielsen 1976; Nielsen and Gregory, in press). "Cold-sensitive" mutants of various microorganisms had been isolated previously but such mutants had minimal growth temperatures only a few degrees higher than that of the parent (Waldron and Roberts 1974). It proved to be possible to isolate cold-sensitive mutants of *A. fumigatus* I-21 sequentially, such that the fifth mutant in the series (designated ON5) had the desired minimal growth temperature (Fig. 1). Whereas it would be impossible for such a mutant to infect man, all the mutants isolated so far are capable of back-mutating to the ability to grow at 37 °C, at a frequency of about 10^{-6}. A major effort is now underway in our laboratory to obtain 37 °C-sensitive mutants with multiple lesions so that revertants would not arise. If these experiments are successful it should be possible to apply the techniques to other thermotolerant fungi and produce cultures that are unequivocally safe. Until such safety is assured we cannot recommend the practical use of *A. fumigatus* I-21 or *R. chinensis* 180 for SCP production. Several other investigations are using fungi that, while not highly thermotolerant, are able to grow well at body temperature. It might be well to consider the possibility that such cultures could be a biohazard.

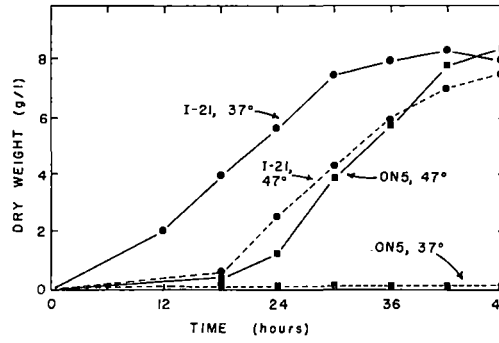


Fig. 1. Growth of A. fumigatus I-21 and its cold-sensitive mutant ON5 in cassava mineral salts medium (2% carbohydrate) at 37 and 47 °C (data from Nielsen 1976).

This work was carried out with the aid of a grant from the International Development Research Centre.

Fermentor Performance in Microbial Protein Production from Cassava[1]

A. G. Meiering and F. A. Azi[2]

A self-aspirating fermentor was developed on the basis of the Waldhof principle. Aeration capacity and microbial growth kinetics were analyzed for the batch and continuous flow process. Design data for a multiple stage continuous flow system were derived using the kinetic models and measured batch fermentation results in computer simulations.

Interdisciplinary research on microbial protein production from whey and cassava, a high yielding tropical root crop with very low protein but high starch content, was begun in 1971 at the University of Guelph. The whey project was aimed at the conversion of residual waste nutrients to yeast protein. The cassava project was performed under contract with the International Development Research Centre in close cooperation with the Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. The engineering objective in the cassava project was to develop a fermentor system and a biomass harvesting system suitable for eventual use on farm or cooperative levels. This required direct cooperation with the participating research group in microbiology, which developed the microbes for the fermentation process and thus provided elementary design data for both, fermentor and separator.

Development of Fermentor

Identical fermentors, employing the Waldhof principle for the injection of air into the fermenting substrate, were used in both projects (Solomons 1969). Fig. 1 shows that the air was conveyed through the hollow shaft and impeller and then dispersed into the liquid through the action of the impeller blades, which act as a sparging vacuum pump for air (Azi et al. 1975). At the same time, it served as a liquid pump, inducing a downward flow of the substrate inside the draft tube and an upward flow between the draft tube and the vessel. The draft tube was jacketed to serve as a heat exchanger for initial steam heating of the medium as well as thermostatically controlled water cooling during fermentation. Fermentors with working capacities of 20, 120, 200, and 3000 litres were built having the same relative dimensions $D_F/H_O = 0.58$ for the fermentor vessel.

The aerating capacity of the impeller is illustrated in Fig. 2 with performance data measured at the 20 litre model. Air flow Q and power uptake P can be readily defined by the following exponential functions of rotor speed N and impeller diameter D_I (Azi 1976).

$$[1] \qquad Q = C_1 D_I^4 N^3$$

$$[2] \qquad P = C_2 D_I^4 N^{2.5}$$

The total air flow not only increased with impeller speed but also with the substrate height in the fermentor up to a point close to the equilibrium between the static potential of this height and the total potential developed by the impeller (Azi et al. 1975; Azi 1976).

The power input per litre substrate at given air flow rates increased and the rotational speed of the impeller decreased with increasing impeller diameters. A diameter of $D_I/D_F = 0.36$ provided proper substrate pumping and mixing in the vessel as well as adequate air flow rates at typical speeds between 800 and 1600 rpm and substrate filling levels between 0.66 and 0.75 H_O. Higher rotational speeds of smaller impellers improve the convective transfer of oxygen into the substrate through higher Nu-numbers and larger specific transfer areas due to smaller bubble sizes (Azi et al. 1975). At the same time, however, the shearing action of the blades is intensified, impairing microbial growth. The larger yeast cells and fungal mycelium were found to be especially sensitive to this action in the early fermentation stages.

The medium-size impeller with $D_I/D_F = 0.36$ required up to 5% more energy than the

[1]This project was financed by the International Development Research Centre in a contract with the University of Guelph. Further financial support was received in the form of an Operating Grant from the National Research Council of Canada.

[2]School of Engineering, University of Guelph, Guelph, Canada, and Engineering Division, Ministry of Agriculture and Natural Resources, Enugu, Nigeria, respectively.

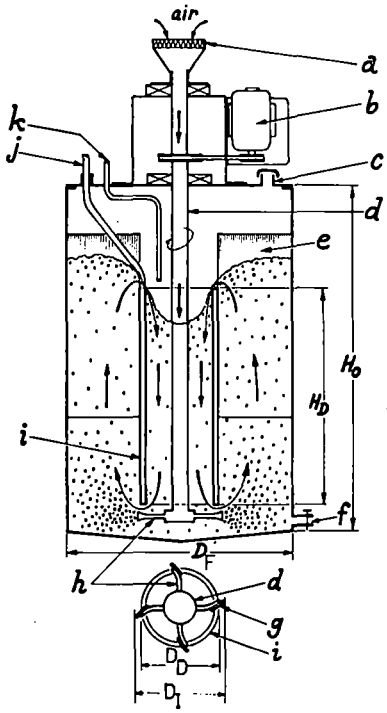


Fig. 1. Cross section through Waldhof-type fermentor: a filter; b motor and belt drive; c valve; d hollow shaft; e baffle; f outlet; g impeller; h impeller arm; i jacketed draft tube; j heating and cooling connections; and k substrate feed.

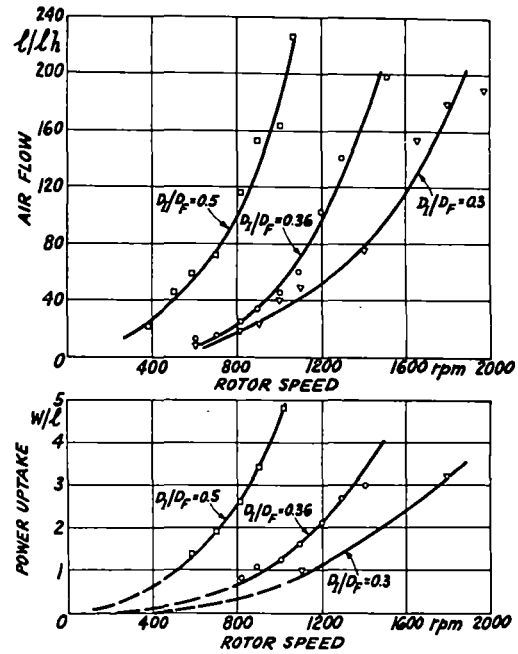


Fig. 2. Effect of impeller diameter on aerating intensity and power uptake of 20 litre fermentor. Substrate: water; fermentor dimensions: H_0 = 45 cm, D_F = 30 cm, H_D = 30 cm, D_D = 10 cm (Azi 1976).

smaller one with D_I/D_F = 0.3, but 10–18% less than the larger one with D_I/D_F = 0.5. Most of the measurements needed for the selection of a proper impeller diameter were systematically taken in water and later repeated at random in various fermentation substrates (Azi et al. 1975; Azi 1976). Reasonably good agreement between these varying materials was observed. Taking all the results into consideration, an impeller diameter of D_I/D_F = 0.36 was chosen for the fermentation program.

Experimental Program

An asporogenous mutant (I-21A) of *Aspergillus fumigatus* was developed as a prototype for fungal cassava fermentations (Reade and Gregory 1975; Gregory et al. 1976, 1977; Gregory 1977). Between 7 and 10% inoculum was added to the prepared substrate. The cassava substrates were prepared by adding 13.3 kg of ground cassava roots to 50 litres of water. This mixture was then heated to 75 °C for 10 min by steam injection to the draft tube, to allow starch gelatinization and the elimination of some fungistatic effects (Reade and Gregory 1975). Another 50 litres of water were then added to adjust the initial carbohydrate concentration to approximately 40 g/litre and the initial substrate temperature to 45 °C. The cassava was replaced by sucrose in several experiments with fungi to minimize expenses and allow fungal biomass weights to be assayed free of cassava fibre. Concentrations of 40 and 50 g/litre were used to match whey and cassava concentrations. Minerals, phosphorus and nitrogen were added in the form of inorganic salts, urea, and corn steep liquor (see Gregory 1977).

The acidity of the cassava substrate was kept at a constant pH of 3.5 through sulfuric acid addition and the substrate temperature was kept at a constant 45 °C. These extreme growing conditions prevent the growth of contaminants and eliminate the need for an air filter. Foaming rarely occurred in initial fermentation stages and could be easily controlled through the addition of a food accept-

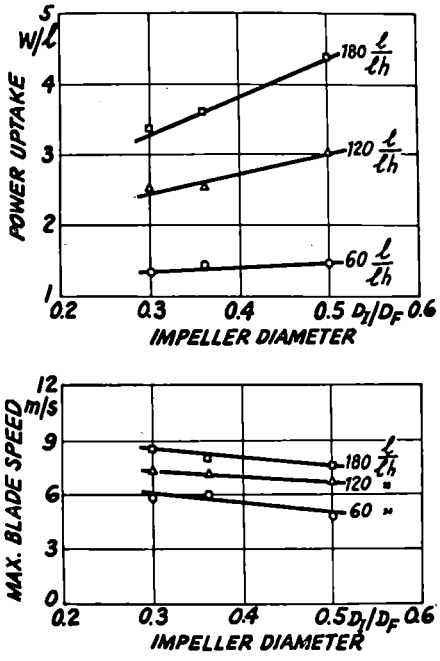


Fig. 3. Effect of impeller diameter on power requirements and impeller velocity. Substrate: water; fermentor dimensions: $H_0 = 45$ cm, $D_F = 30$ cm, $H_D = 30$ cm, $D_D = 10$ cm.

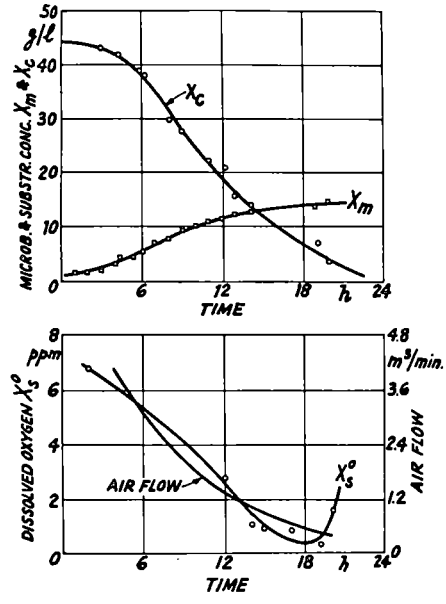


Fig. 4. Batch fermentation results of A. fumigatus I-21A in sucrose solution. Initial carbohydrate concentration 42 g sucrose/litre; substrate temperature 45 °C; impeller speed N = 800 rpm or v =13.3 m/s; fermentor size 3000 litres (Azi 1976).

able antifoam agent to whey and of small amounts of cotton seed or corn oil to the cassava substrates. Most experiments were performed with the 20 and 120 litre fermentors. They were supplemented by several runs in the 200 and 3000 litre commercial models designed for larger scale swine feed production.

Substrate samples were taken at regular intervals during all fermentation experiments and analyzed for viscosity, microbial concentration, substrate concentration, and protein yields (Reade and Gregory 1975; Gregory et al. 1976, 1977). The dissolved oxygen concentration was measured at the same time. Energy consumption of the impeller and air flow were measured in the 20 litre fermentor, which was equipped with a torque meter and a flow meter. The feed value of the biomass was determined in rat experiments (Khor 1974; Khor et al. 1976).

Fermentor Performance

The fermentor performance is characterized by the conversion rate of substrate to microbial protein (Humphrey 1974; Kihlberg 1972; Manouselis 1976; Nordström 1974; Perzow 1974; Reade and Gregory 1975; Rogers et al. 1972; Weinshank and Carver 1967). The biochemical kinetics of this conversion depend on several process variables including temperature, nutrient concentration and rotor speed as the most important ones (Aiba et al. 1973; Meiering et al. 1977; Rhodes and Fletcher 1966; Tsao 1968; Weinshank and Carver 1967). An extensive theoretical analysis of the microbial reaction kinetics was performed and computer simulation programs were established for the prediction of batch and continuous flow fermentations of cassava with *A. fumigatus* I-21A (Azi 1976; Meiering et al. 1977; Monod 1942).

Measured data points and simulated reaction curves of the exponential growth phase of a typical batch fermentation experiment are shown in Fig. 4. The initial sucrose content of 40 g/litre, which compared to a similar carbohydrate concentration in the cassava slurries, was consumed after 20 h of fermentation, when a final microbial concentration of 14 g/litre was reached. The air flow decreased significantly with microbial growth, as illustrated in Figs. 4 and 5. Also, the oxygen concentration in the substrate declined sharply and

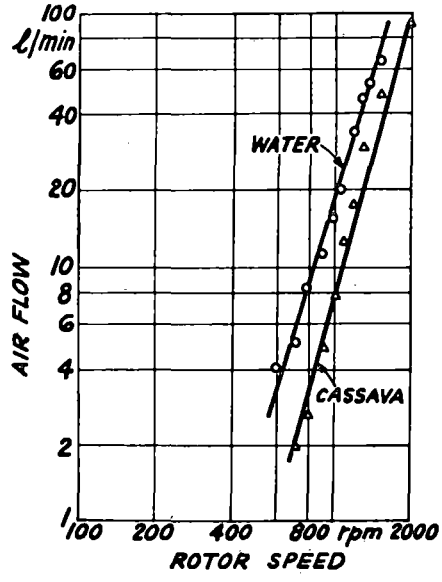


Fig. 5. Air flow through water and cassava slurry taken from 3000 litre fermentor after completed fermentation and measured on 20 litre fermentor. Fermentor dimensions: $H_0 = 45$ cm; $D = 30$ cm; $H_D = 30$ cm; $D_I/D_F = 0.36$ (Azi 1976).

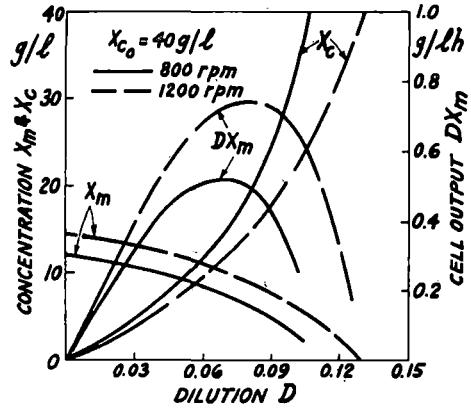


Fig. 6. Continuous flow fermentation results in single stage fermentor. Initial substance concentration 40 g sucrose/litre; substrate temperature 45 °C; impeller speed 1200 rpm or v = 20 m/s.

nearly reached depletion. The total biomass yield was 42 kg in 20 h, amounting to 0.7 kg/m^3 h^{-1} and an energy requirement of 4.97 kwh per kg biomass.

The fermentation results shown in Fig. 4 can be improved in a continuous flow system.

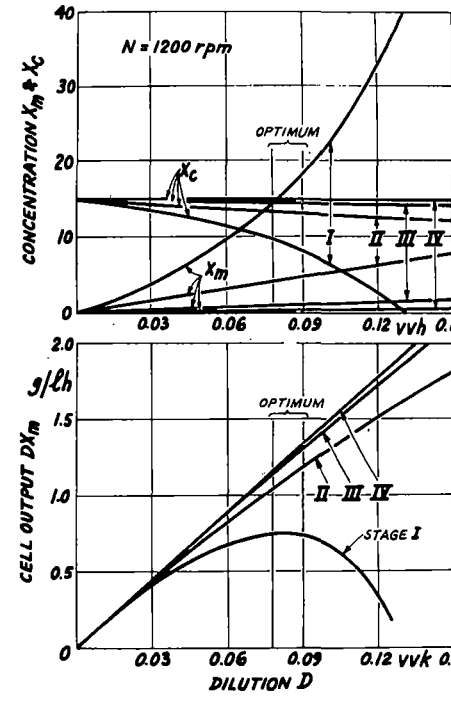


Fig. 7. Fermentation results of A. fumigatus I-21A in a multistage continuous flow system. Initial substrate concentration 40 g sucrose/litre; substrate temperature 45 °C; impeller speed 1200 rpm or v = 20 m/s (Meiering et al. 1977).

It eliminates the lag phase of microbial growth with its initial sensitivity to the shearing action of the impeller (Azi 1976). Slightly higher rotor speeds can, therefore, be used to improve the oxygen transfer and overall growth rate. Fig. 6 shows the results of continuous flow operation for the fermentor used in the batch fermentation example illustrated in Fig. 4. No improvements are achieved, if the single fermentor is operated in the same mode as in the batch process. In fact, the fermentation is incomplete at the highest cell output rate of $DX_m = 0.52$ g/litre h^{-1}, leaving a substrate concentration of approximately 14 g/litre in the effluent. The maximal cell output improves to 7.4 g/litre h^{-1} with a higher rotor speed of 1200 rpm, but approximately the same amount of substrate is lost. A dilution rate of $D = 0.09$ is required for maximal production.

Fig. 7 shows that a sequence of three fermentors is required to limit substrate losses to 1 g/litre at the maximum cell output rate of

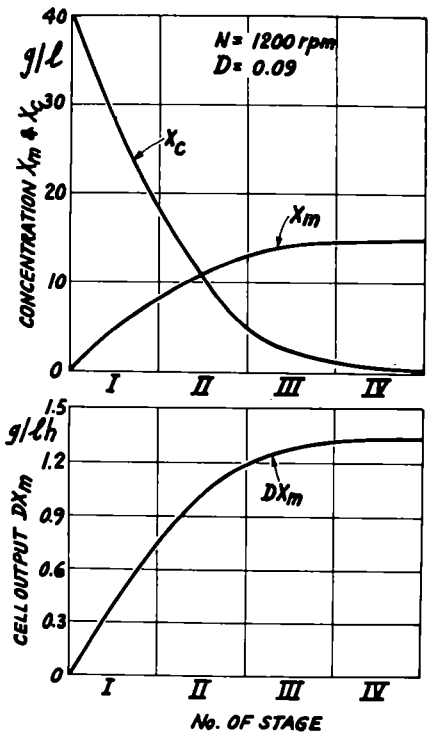


Fig. 8. Fermentation results of A. fumigatus I-21A in a four-stage continuous flow system. Initial substrate concentration 40 g sucrose/litre; substrate temperature 45 °C; impeller speed N = 1200 rpm or v = 20 m/s; dilution rate D = 0.09 in all stages (Meiering et al. 1977).

DX_m = 1.31 g/litre h^{-1} corresponding to dilution rate of D = 0.09 h^{-1}. These substrate losses can be further reduced to 0.22 g/litre in a fourth stage. Fig. 8 summarizes the performance of a multistage system at a dilution rate of D = 0.09 h^{-1}. It shows that the gain in cell output only increases from 1.31 to 1.33 g/litre h^{-1} in the last stage (Meiering et al. 1977).

The total production of a three-stage system would amount to 78.6 kg in a 20-h fermentation period as compared to 42 kg in the 20-h exponential growth phase in the batch system. The batch process requires several hours of inoculate preparation in a separate fermentor. In addition to this, a lag phase of 6–8 h is encountered after transferring the inoculum to the main fermentor. Taking these delays into account as an additional time of 12 h, a ratio of $[(VX_m)_{\text{batch}} / (DX_m)_{\text{cont. flow}}] = 0.33$ would result from comparison of the production potentials of the two systems. This means that a three-stage continuous flow system, as shown in Fig. 9, could operate with 1000 litre vessel capacity in each stage to produce the same amount of biomass as the 3000 litre batch fermentor. Component design for the individual stages would be facilitated by this reduction factor of approximately 66%. Especially, vibration problems of the fermentor shaft, as illustrated in Fig. 10, for the 3000 litre model could be controlled more readily without the proposed installation of an expensive pressure

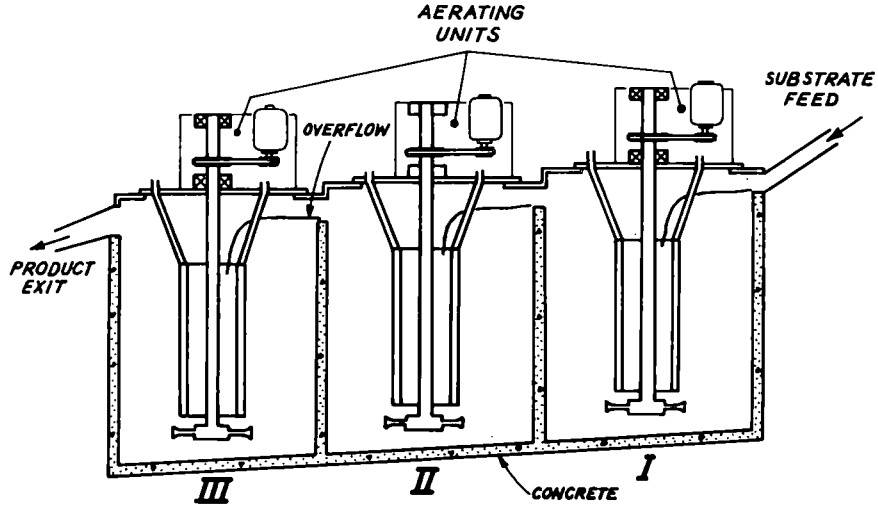


Fig. 9. Layout of 3-stage continuous flow fermentation system with aerating units developed for batch process.

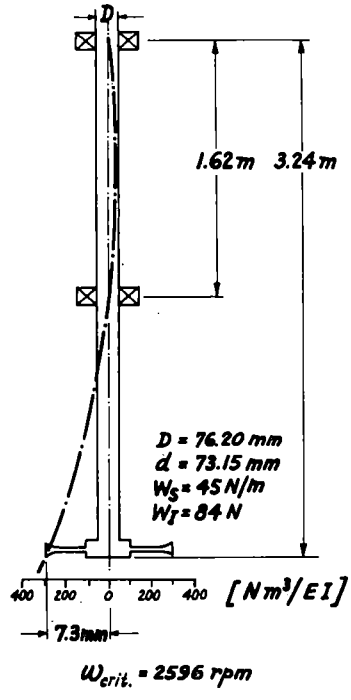


Fig. 10. Shaft deflection in 3000 litre fermentor.

seal and bearing at the vessel bottom. Construction cost could be reduced in both batch and continuous flow systems by using simple containers made of concrete on the farm rather than manufactured stainless steel units. Aerating units of relatively small size could be suspended from a frame construction or the vessel ceiling, as shown in Fig. 9.

Pollution control will likely require a lower carbohydrate content than 1 g/litre in the effluent. The cost of adding a fourth stage in a continuous flow system to satisfy these requirements could render it economically inferior to the batch systems. Another possibility is a progressively higher rotor speed in the sequential stages to improve reaction speed and oxygen supply. Rotor speeds, however, are limited by their shearing action on the microbes. Nevertheless, a limited experiment showed that a fully developed culture can sustain significantly higher speeds than an inoculum in the lag phase (Azi 1976). The behaviour of the culture and the performance of a multistage stage could only be outlined in this report on the basis of batch fermentation data, but should be investigated in an actual pilot scale system.

Laboratory Animal Nutrition with Fungi Grown on Cassava

J. C. Alexander[1]

Various strains of fungi including *Aspergillus fumigatus* were grown on media based on cassava carbohydrate, and evaluated for their nutritional quality, including safety for use as an animal feed. All samples had a low sulfur amino acid level. Biological evaluations included protein efficiency ratio (PER) and net protein ratio (NPR) methods, with male weanling rats. The protein control showed significantly better results for PER, NPR, and weight gain than the fungal proteins. However, by basing the dietary protein on the α-amino acid content, and supplementing it with methionine there was much better performance by the rats. The feeding of *A. fumigatus* resulted in increased relative kidney weights, and at high levels of intake (30 and 40%) more blood urea nitrogen, and a drop in blood albumin. A deficiency in methionine, due to reduced feed consumption, may have contributed to these changes. No significant differences between the control and experimental groups were found by histopathological examinations.

Microorganisms can synthesize protein from substrates such as hydrocarbons and carbohydrates very rapidly (Snyder 1970; Spicer 1973). Hydrocarbons are still available in vast quantities, but as the cost continues to increase, renewable carbohydrate substrates may prove to be economic in certain situations. The greatest need for more food with adequate protein quality and quantity is often in densely populated tropical areas. Cassava (*Manihot esculenta*) is a starch-producing root crop cultivated extensively and almost exclusively in tropical regions of Asia, Africa, and South America as a staple foodstuff (Gutierrez and Anderson 1972). In terms of calories per hectare, its yield is among the highest of any cultivated plant (Martin 1970; de Vries et al. 1970). Because the protein content of cassava is low, its consumption has contributed to malnutrition in areas where it serves as a substantial portion of the diet (Bailey 1961). The average crude protein expressed on a dry weight basis does not exceed 3%, and the quality in terms of essential amino acids is not good (Latham 1965; Hendershott 1972).

In spite of extensive information on the use of cassava in rations for swine (Maner 1972; Gomez et al. 1977), there is still concern about toxicity attributed to its cyanogenic glucosides, particularly linamarin with its potential for production of hydrocyanic acid (Wood 1965; Oke 1969; Nartey 1973). Some studies have shown a correlation of the prevalence of tropic ataxic neuropathy, and endemic goiter with the frequency of dietary intake of cassava (Osuntokun 1973; Ekpechi 1973). In the fermentation of cassava it is detoxified by the liberation of hydrocyanic acid at a low pH (Akinrele 1964).

Gray and Abou-el-soud (1966) investigated microbial protein production from cassava, but did not study the nutritive value or safety of the fermentation products for feeding animals. Other workers (Stanton and Wallbridge 1969; Brook et al. 1969) carried out fungal fermentation of an extruded paste from flour of cassava, and with the genus *Rhizopus* showed a sevenfold increase in protein content of the product over that of the cassava substrate.

Assessment of *Aspergillus oryzae* grown on barley grain by Smith et al. (1975) indicated unsatisfactory results particularly with pig feeding tests. For this and other organisms studied, they reported non-α-amino N levels between 10 and 20% of the total N of the mycelia. Later, Smith and Palmer (1976) evaluated yeasts and bacteria as dietary protein sources for animals. Supplementation with methionine was found to be beneficial. Vander Wal (1976) has reviewed experience with SCP in animal feeding in Europe and Shenderei (1976) comments on experience in the USSR.

Nutritive Value

Studies were carried out by Khor et al. (1976) that demonstrated the nutritive value for rats of thermotolerant fungi grown on cassava. Two strains of *A. fumigatus* (I-21 and I-34), a nonreverting asporogenous mutant of *A. fumigatus* I-21 (I-21A), one strain of *Sporotrichum thermophila* (I-36), and one strain of *Paecilomyces sp.* (I-39) were included.

[1]Department of Nutrition, College of Biological Science, University of Guelph, Guelph, Canada N1G 2W1.

Table 1. The amino acid content of some microbial protein sources[1]

	Source of protein					
	I-21[2]	I-21A[3]	I-34[2]	I-36[2]	I-39[2]	Casein
Aspartic acid	6.0	4.3	5.6	4.7	5.0	7.2
Threonine	3.7	3.7	3.8	3.4	3.2	4.5
Serine	3.9	3.7	4.5	3.1	3.4	5.4
Glutamic acid	7.8	11.4	10.3	8.9	9.6	22.0
Proline	3.4	7.0	3.5	3.2	2.9	11.3
Glycine	5.0	4.3	4.8	3.8	3.8	1.9
Alanine	7.2	5.4	7.7	7.8	7.1	3.0
Valine	5.4	4.6	5.0	4.2	4.2	6.5
Cystine[4]	0.7	0.3	0.5	0.6	0.6	0.4
Methionine[4]	1.4	1.3	1.4	1.1	1.3	2.9
Isoleucine	4.5	3.6	4.3	3.5	3.7	5.7
Leucine	7.1	6.0	6.6	5.5	5.7	9.3
Tyrosine	2.8	2.6	2.9	2.4	2.4	5.5
Phenylalanine	4.8	3.5	4.5	3.7	3.8	5.3
Lysine	7.0	5.3	6.3	5.6	5.6	8.3
Histidine	1.3	1.5	1.5	1.2	1.2	3.0
Arginine	5.8	5.0	6.0	5.4	5.7	3.8
Tryptophan[5]	1.0	—	1.0	1.2	0.8	1.7

[1]Values are averages of duplicate analyses expressed as g/16 g nitrogen.
[2]Substrate: cassava extract medium.
[3]Substrate: whole cassava medium; product contained unfermented cassava residues.
[4]Microbiological assay.
[5]Not done for I-21A.

Gregory et al. (1976) reported the conversion of carbohydrates to protein by high temperature fungi, and the methods of Reade and Gregory (1975) involving high temperature, low pH fermentations, and a self-aspirating fermentor developed by Azi et al. (1975) were used. The medium was heated to 80 °C for 30 min during preparation. Fermentations were carried out nonasceptically at pH 3.5 and 45–50 °C for 20 h. The mould mycelia were recovered by filtration, washed once by resuspending in deionized water (0.5 × culture volume), and freeze-dried. Samples were hydrolyzed with nitrogen-saturated HCl in sealed tubes at 110 °C for 24 h. These hydrolyzates were analyzed for amino acids by ion-exchange chromatography. Values for methionine, cystine, and tryptophan were low, due to loss by this method, so alternate methods were applied. For the two sulfur-containing amino acids a microbiological technique using *Leuconostoc mesenteroides* was carried out. Tryptophan was determined by a spectrophotometric procedure involving hydrolysis by BaOH, and colour development by *p*-dimethylaminobenzaldehyde. Values for amino acid content of the microbial protein sources are shown in Table 1. The low levels of sulfur amino acids in the fungus samples are apparent. The other amino acids were in a more favourable balance. Proximate analyses are in Table 2. The first four fungi were grown on a cassava extract medium, and data were quite similar except that I-21 was higher in lipid content. For the one sample grown on whole cassava medium (I-21A), levels of lipid and crude fibre were relatively low, but the calcium content was increased.

Protein quality was evaluated by Protein Efficiency Ratio (PER) and Net Protein Ratio (NPR) techniques. The animal diet consisted of 10% corn oil, 4% mineral mixture, 1% vitamin mixture, 5% celluflour, and 80% corn starch. The level of corn starch added depended upon the amount of casein or microbial protein used at the expense of the corn starch to provide 10% protein in the diet (see Table 3 for results). For statistical analyses of the data, values with common superscripts are not significantly different ($p < 0.05$) by Duncan's multiple range test. Animals fed the supplemented casein had the most weight gain, and better average feed efficiency. Fungi I-36 and I-39 gave particularly poor results. Regarding the PER, casein and I-21 were best, but all samples produced similar NPR values.

Table 2. Proximate analyses (%) of some protein sources[1]

	Crude protein	Ether extract	Crude fibre	Calcium	Phosphorus
I-21[2]	40.0	12.2	25.4	0.01	0.82
I-34[2]	41.8	6.6	22.5	0.02	0.97
I-36[2]	37.1	6.6	23.4	—	—
I-39[2]	32.6	8.9	19.3	—	—
I-21A[3]	32.7	2.6	14.8	0.13	0.69

[1]Values are averages of duplicate analyses.
[2]Substrate: cassava extract medium.
[3]Substrate: whole cassava medium; product contained unfermented cassava residues.

Table 3. Fungal mycelia from cassava extract medium compared to supplemented casein as the sole sources of dietary protein based on crude protein content (average results from 10 rats per group).

	Weight gain	Feed efficiency (g feed/g gain)	PER[1] (g gain/g protein)	NPR
I-21	210^{bc}	4.2^{bc}	2.1^{ab}	3.6^{a}
I-34	180^{cd}	4.7^{ab}	1.9^{bc}	3.5^{a}
I-36	129^{e}	5.3^{a}	1.7^{c}	3.4^{a}
I-39	148^{de}	5.5^{a}	1.6^{c}	3.1^{a}
Casein[2]	315^{a}	3.4^{c}	2.5^{a}	3.4^{a}

[1]PER values were normalized relative to a value of 2.5 for the casein standard.
[2]Supplemented with 0.3% DL-methionine and 0.1% DL-tryptophan.

Table 4. Fungal mycelia supplemented with methionine compared with casein as sole sources of dietary protein based on crude protein content (average results from 10 rats per group).

	Weight gain (g)	Feed efficiency (g feed/g gain)	PER[1] (g gain/g protein)	NPR
I-21	155^{c}	7.1^{a}	1.3^{c}	2.5^{c}
I-21 + 0.6% DL-methionine	255^{b}	4.0^{bc}	1.8^{b}	3.4^{b}
I-34	140^{c}	6.6^{a}	1.2^{c}	2.7^{c}
I-34 + 0.6% DL-methionine	230^{b}	4.0^{bc}	1.8^{b}	3.4^{b}
Casein[2]	346^{a}	2.9^{c}	2.5^{a}	4.2^{a}

[1]PER values were normalized relative to a value of 2.5 for standard casein.
[2]Supplemented with 0.3% DL-methionine and 0.1% DL-tryptophan.

Analyses had shown that the microbial proteins were low in methionine, and it was considered that supplementation of the test diets with DL-methionine might improve the performance of these proteins. Beneficial effects were seen (Table 4) for *A. fumigatus* strains I-21 and I-34 as illustrated by higher PER and NPR values, as well as better weight gains and feed efficiencies. Nevertheless, in spite of the extra methionine added to the fungal proteins, the supplemented casein still performed better.

Further studies based the protein level of the diets on the α-amino acid content, because a portion of the nitrogen in microbial proteins is contributed by nonprotein sources such as nucleic acids. The results in the upper portion of Table 5 show that I-21 and I-34 as supplemented, produced comparable feed efficiency and NPR values to those for the casein. Weight gains and PER values were, however, lower. A different experiment produced the results in the lower part of Table 5. Here I-21A was grown on whole cassava medium, and the product contained unfermented cassava residues. The casein was not supplemented, but still performed relatively

Table 5. Fungal mycelia and fermented cassava compared with casein as sole sources of dietary protein based on α-amino acid content (average results from 10 rats per group).

	Weight gain (g)	Feed efficiency (g feed/g gain)	PER[1] (g gain/g protein)	NPR
I-21 + 0.6% DL-methionine	226[b]	4.8[a]	2.2[b]	3.6[a]
I-34 + 0.6% DL-methionine	210[b]	4.7[a]	2.0[b]	3.4[a]
Casein + 0.3% DL-methionine + 0.1% DL-tryptophan	392[a]	2.8[a]	2.5[a]	3.8[a]
Cassava fermented by I-21A	83	4.5	1.5	3.2
Casein	153	2.6	2.5	5.0

[1]PER values were normalized to a value of 2.5 for the casein standard.

better than the fermented cassava. Nevertheless, note the low weight gains for casein alone as the protein source.

The rats fed I-21A grown on the whole cassava medium had very poor growth during the first week of the experiment (Fig. 1). Because feed intake was comparable to that for the casein-fed animals the poor growth performance resulted from inefficient utilization of the feed. For example, the feed efficiency during the first week was 2.4 for the casein group, and 10.7 for the I-21A. During this time there was considerable variation in weight gain response by individual animals within the I-21A dietary group, indicating that the rats did not adapt readily to the diet. After the initial lag period, the growth rate improved greatly (Fig. 1).

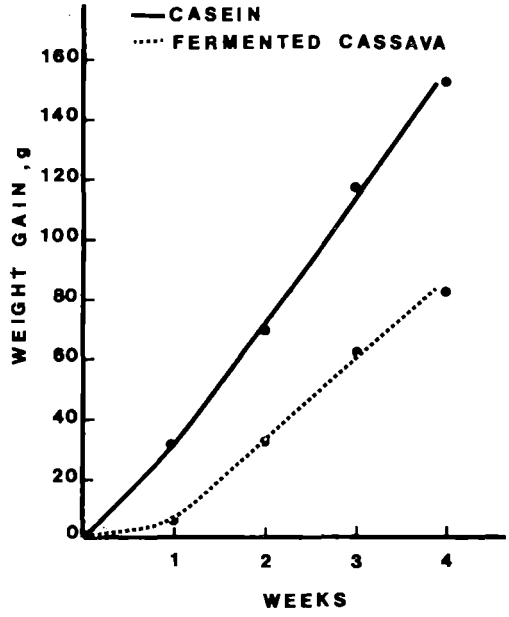


Fig. 1. Weekly weight gains by rats fed casein or cassava fermented by A. fumigatus I-21A.

Safety Evaluation

It was recognized that the fermentation products from fungi grown on cassava should be subjected to rigorous toxicological examination prior to feeding them to farm animals. The Protein-Calorie Advisory Group of the United Nations System (PAG) has issued official guidelines for systematic clinical testing of new protein sources (PAG Guideline No. 6 1970; PAG Statement No. 4 1970; PAG Guideline No. 15 1974). The *A. fumigatus* I-21 studied for nutritive value (Khor et al. 1976) was subjected to a safety evaluation for use as an animal feed (Khor et al. 1977).

There were 10 male weanling rats per group and all diets and water were offered ad libitum. The test groups received the fungus sample at levels of 20, 30, or 40% of the ration, whereas the control group was provided with soybean oil meal as the sole source of protein. The protein contents of the test diets were brought to the same level as that in the control diet (18% crude protein) by addition of soybean oil meal (Table 6). The rats were maintained on these rations for 90 days, then killed, and autopsied. Body weight and feed consumption data were obtained, and extensive clinical and histopathological examinations were carried out.

Table 6. Composition of diets (g/kg) for the subchonric toxicity study of *A. fumigatus* I-21.

	Control diet	Fungus diets		
		20%	30%	40%
Soybean oil meal	408	263	190	117
Fungus I-21	—	200	300	400
Mineral mixture	40	40	40	40
Vitamin premix	20	20	20	20
Corn oil	60	60	60	60
Celluflour	10	10	10	10
Corn starch	458	403	376	349
DL-methionine	4.0	4.0	4.5	4.5

The average body weights were consistently higher for the control diet than for the fungus diets (Table 7). However, there was no statistical difference in weight gain throughout the experiment between the rats fed 30 and 40% fungus, but both of these groups were lower than the 20% fungus group. The control animals ate more feed but there were no important differences in feed efficiency data.

In general, none of the organ weights, except for the kidneys, showed significant differences between fungus-fed groups and the control group (kidney weights (g/100 g body weight) were: soybean oil meal 0.81; 20% I-21 0.95; 30% I-21 1.01; 40% I-21 0.98). The blood glucose and glutamic-pyruvic transaminase concentrations were not altered by feeding the fungus diets, but urea nitrogen levels tended to rise at the higher levels of intake (soybean oil meal 20; 20% I-21 20; 30% I-21 22; and 40% I-21 24 mg urea N/100 ml). The glutamic-oxaloacetic transaminase, and alkaline phosphatase showed no relationship to dose level. Rats fed 30 and 40% of *A. fumigatus* I-21 had a significant drop in serum albumin (Table 8) but other serum protein values were not changed.

Blood values obtained at termination of the feeding study were not remarkable except for small changes in leukocyte counts, and urine samples showed normal colour, and tests for glucose, acetone, bilirubin, protein, pH, and blood. Kidney function tests revealed that rats in all groups were able to concentrate their urine when deprived of water. Histopathological examinations of many tissues indicated no significant differences between the control and test groups.

Discussion

Microbial proteins in general have a low methionine content, and supplementation with this amino acid is necessary to obtain a protein quality approaching those of animal sources. Early studies (Skinner and Müller 1940; Klose and Fevold 1945) revealed that

Table 7. Body weight, feed consumption, and feed efficiency of rats fed soybean oil meal or *A. fumigatus* I-21 at different dietary levels.

	Body weights (g)			Feed consumption (g/rat/day)			Feed efficiency (g feed/g gain)		
	4 wk	8 wk	12 wk	4 wk	8 wk	12 wk	4 wk	8 wk	12 wk
Soybean oil meal	247[a]	335[a]	357[a]	17.3[a]	19.2[a]	18.7[a]	2.8[b]	6.3	21.9
20% I-21	211[b]	272[b]	277[b]	14.3[b]	14.8[b]	13.8[b]	2.9[b]	7.2	34.8
30% I-21	190[c]	243[c]	245[c]	13.3[b,c]	13.9[b]	12.2[b]	3.2[a]	8.1	34.2
40% I-21	176[c]	241[c]	241[c]	12.5[c]	13.6[b]	12.5[b]	3.5[a]	10.3	38.9

Table 8. Plasma protein values for rats fed soybean oil meal or *A. fumigatus* I-21 at different dietary levels for 90 days.

	Total serum proteins (g/100 ml)	Serum albumin (g/100 ml)	Serum globulin (g/100 ml)	Albumin / Globulin
Soybean oil meal	6.0	4.2[a]	1.9	2.2
20% I-21	6.0	3.9[a,b]	2.0	2.0
30% I-21	5.9	3.7[b]	2.1	1.8
40% I-21	5.6	3.6[b]	2.0	1.8

both moulds and yeast gave much improved performance as protein sources for rats if supplemented with methionine. Bressani (1968) reported a dramatic improvement in PER when 0.5% DL-methionine was added to torula yeast. Also, *Candida lipolytica* grown on alkanes had a higher biological value when supplemented with 0.3% DL-methionine (Shacklady and Gatumel 1972).

In the study of Khor et al. (1976) the strains of *A. fumigatus* tested produced better results if supplemented with methionine and evaluated by weight gain of rats, feed efficiency, PER and NPR values. There was, however, considerable variation in feed intake among rats maintained on diets containing the fungi. When rations are offered ad libitum, many factors contribute to the amounts of feed actually consumed. The flavour, dry texture, and nutritive balance of the microbial proteins could have adversely affected the intake of feed. When growth is to be compared, a difference in feed intake makes conclusions regarding composition of the rations more difficult. Consequently, PER calculated from the results of ad libitum feeding at a 10% level tends to penalize the less palatable protein source.

With a substantial portion of the microbial nitrogen in the form of nonprotein nitrogen, unless the dietary protein level is based on α-amino nitrogen, the fungal proteins are penalized further.

The increase in kidney weights relative to body weights of rats fed *A. fumigatus* I-21 was not accompanied by pathological changes. Therefore, this increase was considered to be a response to metabolic requirements. The tendency toward an elevation in blood urea nitrogen with an increase in the fungus level in the diet could indicate an imbalance of amino acids in these rats as a result of decreased feed intake. Thus, excess amino acids would have to be deaminated. Nitrogenous substances in the fungi such as glucosamine in the cell wall, and nucleic acids would also contribute to urea nitrogen.

Selye (1950) has explained that many types of dietary deficiencies could act as stressor agents in exerting effects upon blood components. The highest levels of fungus could have resulted in some measure of stress, related to the decreased feed intake and possible deficiency of methionine. This might have depressed the albumin synthesis, and exerted a physiological influence on the ACTH to bring about small changes in the leukocyte counts. Volesky et al. (1975) fed diets containing fungus grown on natural gas to rats for 5 months. They found growth depression, decreased leukocyte counts, and increased kidney weights, but no pathological changes were observed at autopsy.

Pilot Plant for Single-Cell Protein Production

J. Santos N. and G. Gómez[1]

A process for microbial protein production, using cassava as the energy substrate, was developed and tested at a laboratory scale at the University of Guelph. The microorganism used was the fungus *Aspergillus fumigatus* I-21A an asporogenous mutant that could grow under very selective conditions of temperature (45 °C) and pH (3.5). A pilot plant has been built at CIAT to test the technology developed, at a laboratory scale, and to produce a sufficient quantity of biomass for practical evaluation in animal feeding, notably in swine. Preliminary results obtained at the pilot plant are reported, suggesting a potential of the process once completely safe operational procedures can be established. A feeding trial with fungal biomass obtained at the pilot plant indicates that the product has a good nutritive quality if methionine is adequately supplemented.

Root crops including cassava (*Manihot esculenta*) are commonly grown throughout the tropics for food and contribute a considerable proportion of the total caloric intake of the human population (FAO 1973). Cassava has become the staple food of more than 200 million people throughout the tropics (Coursey and Haynes 1970).

The prospects for increasing cassava production in tropical areas are very promising, not only as a consequence of an increase in the area planted in cassava but notably as a result of improved technology, which suggests that drastic improvements in crop yield could be readily obtained by appropriate genetic selection and cultural practices (CIAT 1975, 1976).

Because pigs are efficient converters of the high energy content of cassava roots, the greatest possible increase in cassava utilization as an animal feed is most likely to occur in swine feeding. Extensive experimental information is available on the use of cassava roots in swine feeding.

The most important factor for determining the use of cassava as an animal feed is its price in relation to alternate energy sources and its dependence on the price of supplementary protein sources (Phillips 1974). Because of its low protein content as compared with cereals, any substitution of cassava (fresh, ensiled, or dried) for cereals in mixed feeds would be accompanied by an increased requirement of supplementary protein. Experimental data indicate that a life-cycle feeding program for swine based on the use of cassava meal or flour requires approximately 60–65% more protein supplement (soybean meal) than a similar feeding program based on common maize (Gómez et al. 1976). Therefore, the potential of cassava as an animal feed in the tropics will depend to a great extent on the availability of conventional protein or on the development of new protein sources.

Conventional protein sources such as fish meal and soybean meal, although being used increasingly for human nutrition, are becoming so high in price that their use in swine feeding will be restricted in the future. Other protein sources such as cottonseed meal are of limited use because of their toxic nature. In addition, in many cassava-producing areas it is difficult to grow other crops (i.e. soybeans) that will provide the protein required to balance the animal feeding programs adequately. The need to find alternate nonconventional feed proteins is becoming increasingly important.

The process for converting cassava into microbial protein is an attractive area of research for those cassava-producing areas where animal production — notably swine — could be significantly increased. The production of microbial protein from cassava would substantially upgrade the value of the feed and result in a nutritious product.

The existence of both a cassava program and a swine production unit at CIAT makes it especially advantageous to undertake a project for the production of a fungal protein on a pilot plant scale. CIAT has completed the construction of this pilot plant to study the different aspects involved in the production of fungal protein using cassava as a substrate. This work is being done in cooperation with the University of Guelph under the auspices of the International Development Research Centre of Canada.

[1]Centro Internacional de Agricultura Tropical (CIAT), Apartado Aéreo 67-13, Cali, Colombia.

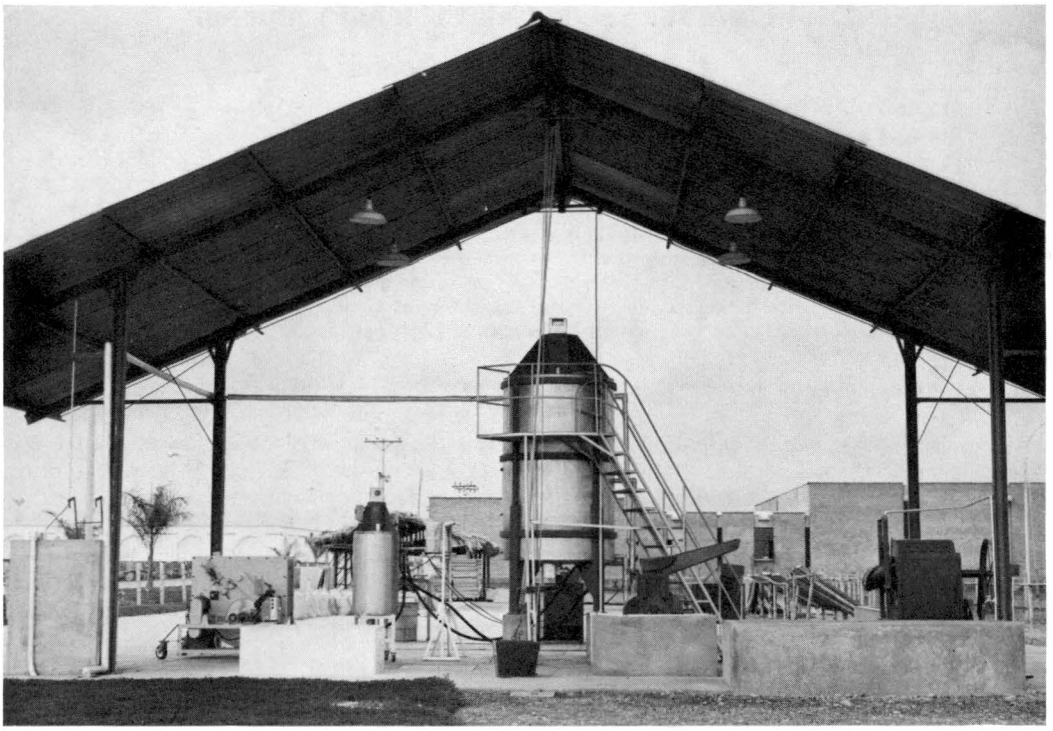


Fig. 1. The pilot plant used to produce microbial protein using cassava roots as the energy source at the CIAT swine unit.

The Pilot Plant Process

The pilot plant at CIAT was built during 1976 and began operating by early 1977 (Fig. 1). The following equipment has already been installed: a washer, a rasper, two self-aspirating fermentors (the starter and main fermentors with working capacities of 200 and 3000 litres, respectively) and a roller-press harvester. The first two machines, built in Colombia, are normally used in the starch factories found around the Cauca Valley. The two fermentors and the biomass harvester were designed and built at the University of Guelph. The characteristics of the fermentors have been described elsewhere (Azi et al. 1975). A single-cell protein (SCP) laboratory has also been allocated and equipped in a locale adjacent to the pilot plant. A Microferm, 10-litre bench-scale fermentor (New Brunswick Scientific Co., New Brunswick, N.J.), designed for batch fermentations and continuous culture of microorganisms, was installed in the SCP laboratory. In addition, accessory facilities consisting of racks and wooden trays for sun and air drying of the biomass are located in an area adjacent to the pilot plant.

A detailed description of the basic aspects of the process was given by Reade and Gregory (1975). The process was designed to operate with a minimum of instrumentation. The parameters for monitoring culture growth are temperature, pH, and dissolved oxygen. Although these parameters would not necessarily be required in practical production units, they facilitate research in that they confirm experimental information obtained on a laboratory scale at the University of Guelph. Both fermentors were provided with side openings for the insertion of instrument probes, which are controlled by means of a master switch box. The composition and preparation of the medium for the laboratory, the 200, and 3000 litre fermentors are basically the same as previously described (Reade and Gregory 1975).

The pilot plant process starts with either fresh cassava roots or cassava meal or flour. When fresh roots are used, they are washed to remove the soil and sand clinging to the outside. Next, the whole roots including the peel

are rasped to break open the cell walls to facilitate the suspension of the starch granules in the fermentation medium. The rasped cassava is then transferred to the fermentor, which is then half filled with water previously heated to about 70 °C by the passage of steam through a heat exchanger; in the case of the large (main) fermentor, a hoist and bucket arrangement is used to lift the rasped cassava. The high temperature of 70 °C needs to be maintained for about 10 min to gelatinize the starch and prevent the development of fungistatic activity in the mash (Reade and Gregory 1975; Gregory et al. 1976). More water is added to the tank to bring the fermentor almost to its full operating volume, as well as to lower the temperature of the fermentation medium to about 46–47 °C. The remaining ingredients necessary to complete the adequate nutrient supply for optimal growth of the microorganisms are urea and monopotassium phosphate, which are added to the medium while stirring. Sulfuric acid (9 *N*) is then used to bring the initial pH of the medium to 3.5. The fermentor is now ready for inoculation of the microorganism. Fermentation is usually completed within 20 h; temperature is maintained throughout the fermentation period by means of a temperature controller, which actuates a solenoid-controlled water valve to regulate the flow of cooling water at ambient temperature. At the end of the fermentation period, the biomass is harvested and can be fed fresh or sun/air dried to be subsequently incorporated into composite diets for animal feeding (Fig. 2).

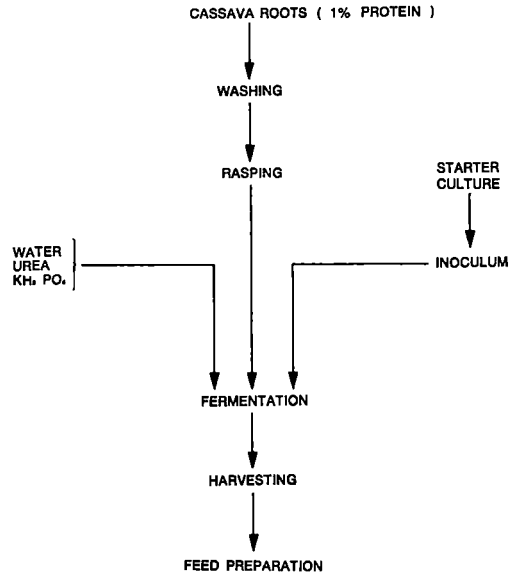


Fig. 2. Flow diagram of cassava single-cell protein fermentation.

Standardization of the process was done with the 200-litre fermentor using either fresh cassava roots or cassava meal. Because people working in the pilot plant might be allergic to or infected by spores from revertants of the asporogenous *Aspergillus fumigatus* I-21A or by hyphal fragments (Sidransky 1975), special safety precautions have been taken so preliminary observations, as well as the work under way, are being obtained with the 200-litre fermentor. Use of the 3000-litre fermentor awaits better defined safety precautions, from a microbiological aspect (Gregory 1977), as well as from experimental results at CIAT's pilot plant.

Preliminary Results

The microorganism used was *Aspergillus fumigatus* I-21A (ATCC 32722) (Reade and Gregory 1975). This fungus is an asporogenous mutant; therefore, the problem of aspergillosis (inhalation of spores) is practically eliminated or significantly reduced. Although a biomass harvester is now installed in the pilot plant, the information presented herein was obtained without the use of this machine; the harvesting of the final biomass was performed by emptying the contents of the fermentation tank into burlap sacks and squeezing it to remove the water, first manually and then with a wine press to obtain a partially dried product, which was placed on wooden-framed trays for further drying by exposure to sun and air.

Average data from fermentations with the 200-litre tank, using either fresh chopped cassava roots or cassava meal or flour as the substrates, are shown in Table 1. The amount of either fresh roots or cassava meal used in each fermentation was determined by the content of total carbohydrates of the substrate so as to obtain an initial carbohydrate concentration in the fermentation medium of approximately 4% (w/v). The yield of the dried biomass was similar for both substrates when expressed on a dry matter basis. The crude protein content of the final dried product was about 28%, which is lower than that reported for laboratory results (Reade and Gregory 1975; Gregory et al.

Table 1. Results of fungal protein (*Aspergillus fumigatus* I-21A) production in a 200-litre fermentor using fresh roots or cassava meal as substrates.

Fresh cassava roots[1]	
Amt. of cassava mash (kg)	25.3
Amt. of sun-dried biomass obtained (kg)	4.4
Product yield (g/litre)	22.2
Yield: weight of dried biomass in relation to	
Fresh cassava (%)	16.9
Cassava, dry matter basis (%)	48.5
Crude protein content in dried biomass (%)	28.6
Cassava meal[2]	
Amt. of cassava meal (kg)	11.5
Amt. of sun-dried biomass obtained (kg)	5.4
Product yield (g/litre)	27.0
Yield: weight of dried biomass to cassava meal (%)	47.0
Crude protein content in dried biomass	28.2

[1]Mean of 10 fermentations.
[2]Mean of 5 fermentations.

1976). The biomass, when water was partially extracted with a wine press, was dried easily when exposed to sun and air; the material became dark and hard when dried in an oven.

A biological evaluation with growing rats was performed to ascertain the nutritive quality of the total or crude protein content of the dried biomass resulting from fermentations with either fresh roots or cassava meal as substrates. Since this fungal protein has been reported (Gregory et al. 1977) to be deficient in sulfur-containing amino acids — notably methionine — the effect of the addition of this amino acid was also studied. Table 2 presents the experimental results obtained with growing rats. Total weight gains over a 28-day experimental period were very poor for the diets based on the unsupplemented biomass; methionine supplementation significantly improved the protein quality of the fungal protein, resulting in body weight gains similar to those obtained with casein and superior to soybean meal protein. PERs (protein efficiency ratio: g body gain/g protein consumed) were adjusted so that standard casein was used as a reference with a value of 2.5; methionine-supplemented microbial protein exhibited adjusted PER values similar to those for casein.

Because of the biohazard for the personnel working at the pilot plant, with regard to aspergillosis derived either from inhalation of revertants producing spores or from hyphal fragments (Sydransky 1975) carried in the aerosols formed at harvesting (Gregory 1977), special safety precautions were taken to reduce risks to a minimum. For these reasons and until completely safe conditions can be assured for the personnel, the fermentation will be carried out in the 200-litre fermentor. There are several aspects that need to be studied with the starter fermentor before progress can be obtained to the extent of using the 3000-litre fermentor. However, despite the present uncertainties, especially as regards safety aspects, the process seems to be very promising for practical application in cassava-producing areas to solve partially the increasing demand for protein supplements for cassava feeding programs, notably for swine.

Table 2. Effect of methionine supplementation on the protein quality of fungal biomass grown on a cassava medium and fed to rats (avg. for 10 male rats per group; 28-day experimental period; avg. initial weight 41.2 ± 2.1 g)

			Biomass produced on			
			Fresh cassava		Cassava meal	
	Control casein	Soybean meal	+ 0.3% methionine	without methionine	+ 0.3% methionine	without methionine
Total feed intake (g)	302.6[a]	308.8[a]	296.0[a]	195.6[b]	323.7[a]	198.8[b]
Total weight gain (g)	78.2[a]	68.2[b]	74.8[a]	24.2[c]	85.0[a]	29.7[c]
Feed/gain	3.9[c]	4.5[c]	4.0[c]	8.5[a]	3.8[c]	6.9[b]
Absolute PER	2.6	2.3	2.5	1.2	2.6	1.5
Adjusted PER (for standard casein 2.5)	2.5[a]	2.2[b]	2.5[a]	1.2[c]	2.5[a]	1.5[c]

NOTE: values with a common superscript are not significantly different.

Whole Plant Utilization of Cassava for Animal Feed

Alvaro Montaldo[1]

Cassava is an important food crop in the tropics. The roots and foliage (leaves and stems) are used both fresh and dry in animal nutrition. The root is a good carbohydrate source (80–90%). The aerial part of the plant is composed of stems, branches, and leaves, and has been shown to have a protein content as high as 17%. Foliage can be cut from the plant at 4 months, and then every 60–75 days to give 4 t of crude protein per hectare per annum.

In Venezuela, cassava meal can be produced for about one-fifth the cost of imported alfalfa meal. By using cassava products for 70% of the rations it is estimated that 6 kg of poultry meat, 5 kg of swine meat, and 200 eggs per person could be supplied to the 2.3 billion people in the tropics using only a fraction of the area that would be required for an equivalent production of animal products based on cereals and oil seed crops.

Cassava is one of the twelve most important food crops in the world in terms of both area planted and total production (105×10^6 tonnes). However, in the low and humid tropics it is second only to rice in importance.

Brazil, Indonesia, Nigeria, Zaïre, Thailand, India, and Burundi are the most important cassava producing countries. Burundi, India, Thailand, and Brazil have the highest mean yields with values of 22.2, 16.5, 14.8, and 12.7 t/ha, respectively.

Comparing mean production and area data during the period 1961–65 with the area and corresponding production figures for the year 1975 (Table 1), it can be seen that in Africa, Asia, and Central America the percentage increase in production has been larger than the increase in the area under cassava cultivation. In South America and the Pacific, however, the increase in area has not resulted in a corresponding increase in production.

Cassava is used in three main ways: (1) for human nutrition; (2) for animal nutrition; (3) for industrial production of starch and its derivatives, alcohols, and as a substrate for single-cell protein production. Phillips (1974) has estimated that by 1980 the EEC could be using 9 million tonnes of pelleted cassava for animal feeding. This represents about 27 million tonnes of fresh cassava roots.

In the last 15 years the culture of cassava has received a great deal of attention because of the rediscovery of the importance of this long-cycle crop, especially its potential as a carbohydrate source for the tropics. Much work has been conducted on physiology, soils, fertilizers, agronomy, breeding, and disease and insect resistance. However, the production of carbohydrates from root crops is still expensive compared with maize and sorghum due to the lack of practical application of good planting material, good and opportune agronomic practices, and appropriate mechanization of planting and harvesting. With the use of cassava foliage as a protein source, new agronomic methods must be developed to allow the permanent cutting of cassava foliage.

The problem of vascular streaking of the roots due to enzymatic activity after 48 h remains unsolved. Another problem is the lack of processing equipment and techniques for medium and large-scale factories specifically designed for cassava.

Cassava Roots as Animal Feed

A transverse section of the reserve root shows two principal divisions: the bark and the central cylinder or pulp. The proportions of bark in the root have been variously reported to be 11–22% (Barrios and Bressani 1967) and 14–21% (Mota 1970). The principal part of the central cylinder is the secondary xylem, which comprises parenchyma, vessels, and fibres. It is this secondary xylem that is the principal storage area for starch.

Carbohydrates

The bark contains higher percentages of crude protein, fat, minerals, and crude fibre than the central cylinder where the highest concentrations of carbohydrates are found (Table 2). Lim Han Kwo (1968) compared the carbohydrate content of cassava root products with that of sorghum and maize (Table 3). The calculated nutritive value of cassava was higher than that of either maize or sor-

[1]Facultad de Agronomía, Universidad Central de Venezuela, Maracay, Venezuela.

Table 1. Total production (t × 10^3) and area under cultivation (ha × 10^3) of cassava (FAO 1975).

	Production			Area		
	1961–65 (mean)	1975	% increase	1961–65 (mean)	1975	% increase
Africa	33662	43972	30.63	5713	6057	6.02
Asia	18416	28814	56.46	2274	2811	23.61
C. America	540	769	42.40	90	116	28.88
S. America	25205	31432	24.70	1934	2547	31.69
Pacific	171	221	29.23	16	20	25.00
World total	77995	105209	34.89	10027	11551	15.19

Table 2. Proximate analysis (%) of the reserve roots of two varieties of cassava (Barrios and Bressani 1967).

	Moisture	Fat	Crude fibre	Crude protein	Ash	Carbohydrate
Papa						
Whole root	66.7	1.02	4.88	2.55	3.30	88.25
C. cylinder	65.6	0.87	3.49	2.03	2.80	90.81
Bark	71.5	1.93	9.16	4.56	4.21	83.45
Chilca						
Whole root	70.2	1.07	6.97	2.68	4.02	85.26
C. cylinder	68.4	1.01	5.12	1.90	3.23	88.74
Bark	71.3	2.89	17.18	5.57	6.00	60.00

ghum. Ketiku and Oyenuga (1970) reported that the cassava root contains sucrose, maltose, glucose, and fructose; sucrose being the most important. Starch constitutes the bulk of the soluble carbohydrate. Sreeramamurthy (1945) studied the digestibility of the carbohydrates and found that in the raw state the value was 48.3% and that after cooking it rose to 77.9%. The starch was digested to a greater extent by "taka" diastase than by pancreatic amylase.

Until recently, the main uses for cassava were as a direct human energy food and as a product for the starch and derivatives industries. Therefore, most of the chemical analyses were made on the central cylinder where the majority of the starch is stored. With the increasing use that is now being made of the entire root for the making of meals and pellets for animal feeding, it is necessary to reconsider analytical values to take into account the products derived from the bark.

Protein

Compared with sorghum and maize, the crude protein level of cassava products (≈2%) is low (Maner 1973). The protein content of refined flour is very low (0.3%) because the product is screened to eliminate all possible remains of bark.

The levels of both total nitrogen and nonprotein nitrogen are higher in the bark than in the central cylinder and the whole root (Table 4). Maner reports that these results do not agree with those found by Oyenuga (1955), who indicated that 62% of the N in the whole root was true protein and that 87% of the nitrogen in the bark was derived from true protein. Splittstoesser and Rhodes (1973) investigated six cassava varieties and reported crude protein values of 1.47–5.18%.

Sreeramamurthy (1945) investigated the N content of cassava and found that most of the N existed as simple nitrogenous compounds. Both the protein and nonprotein fractions contained the amino acids tyrosine, tryptophan, and cystine in fair amounts and had high levels of arginine. The digestibility of cassava root proteins was similar to that of rice protein.

Table 5 indicates that values for crude protein range from 3.93 to 10.05%, with 15 of 20 Venezuelan varieties having values of over 6%. These values are higher than those reported by Maner (1973), Splittstoesser and Rhodes (1973), Sreeramamurthy (1945), Lim

Table 3. Nutritive value of different cassava root products compared with sorghum and maize (Lim Han Kwo 1968).

	On fresh basis								Calculated digestible nutrients				Digestibility coefficient used					
	% moisture	% C. protein	% C. fibre	% sol. carbohy.	% ether ext.	% ash	% total dry matter	% C.P. (dry matter basis)	% C. protein	% C. fibre	% sol. carbohy.	% ether ext.	% C. protein	% C. fibre	% sol. carbohy.	% ether ext.	Starch equivalent	Nutritive value
Cassava root (dry)	12.6	2.0	4.0	75.7	0.69	5.00	87.4	2.3	1.3	3.0	74.2	0.35	66	76	98	50	79.2	60.0
Cassava chips	11.7	1.9	3.0	80.5	0.72	2.17	88.3	2.1	1.3	2.3	78.9	0.36	—	—	—	—	83.2	63.1
Cassava meal	11.2	2.6	5.6	73.9	0.55	6.10	88.6	2.9	1.7	4.3	72.4	0.28	—	—	—	—	78.7	45.5
Cassava (ground)	13.5	2.8	5.0	76.2	0.50	2.00	86.5	3.2	1.8	3.8	74.7	0.25	—	—	—	—	80.7	43.9
Cassava refuse (fresh)	80.0	0.4	1.6	17.6	0.10	0.30	20.0	2.0	0.1	1.3	9.9	0.10	—	—	—	—	11.5	114.3
Cassava refuse (dry)	10.0	1.8	5.0	64.6	0.20	18.40	90.0	2.0	1.2	3.8	63.9	0.10	66	76	99	50	69.0	56.6
Cassava flour	14.9	0.3	0.1	84.4	0.10	0.20	85.1	0.4	0.2	0.1	86.3	0.10	66	100	99	100	84.1	419.6
Sorghum	11.9	7.5	2.0	74.6	2.32	1.65	88.1	8.5	39.0	1.1	48.5	1.35	52	57	65	58	89.5	1.4
Maize (ground)	13.4	9.4	1.9	70.1	3.64	1.62	86.6	10.0	7.4	0.7	64.5	2.18	—	—	—	—	78.2	8.9

Table 4. Total nitrogen (N) and nonprotein nitrogen (NPN) levels of three cassava varieties (Maner 1973).

	Fresh			Dry		Oven dry	
	Moisture (%)	N (%)	NPN (%)	N (%)	NPN (%)	N (%)	NPN (%)
CMC-84							
Whole root	63.9	0.16	0.063	0.45	0.20	0.36	0.18
C. cylinder	64.3	0.12	0.073	0.33	0.17	0.35	0.16
Bark	76.0	0.33	0.160	1.37	0.67	0.78	0.38
CMC-60							
Whole root	70.2	0.14	0.068	0.48	0.23	0.40	0.24
C. cylinder	68.1	0.10	0.066	0.31	0.21	0.32	0.21
Bark	71.9	0.20	0.140	0.71	0.50	0.85	0.46
CMC-11							
Whole root	58.62	0.36	0.240	0.86	0.57	0.69	0.54
C. cylinder	58.24	0.32	0.200	0.80	0.48	0.65	0.46
Bark	64.06	0.41	0.290	1.14	0.81	1.10	0.80

Table 5. Proximate analyses of roots of 20 Venezuelan cassava varieties.[1]

	D.M. 60 °C (%)	D.M. 100 °C (%)	C.P. (%)	Ether ext. (%)	C.F. (%)	Ash (%)	NFE (%)
UCV-2144	32.12	89.93	6.78	0.55	4.66	2.23	85.77
UCV-2187	38.40	90.33	8.08	0.33	3.00	1.86	86.72
UCV-2135	39.05	90.30	6.07	0.51	3.13	1.87	88.40
UCV-2154	36.62	90.33	6.33	0.50	3.28	1.54	88.34
UCV-2134	34.33	89.37	7.38	0.55	2.74	1.68	87.64
UCV-2155	33.05	90.77	7.09	0.83	4.35	1.80	85.93
UCV-2149	35.34	90.73	5.90	0.56	2.53	2.17	89.09
UCV-2192	33.81	90.27	6.03	0.54	3.19	2.07	88.34
UCV-2142	32.23	89.03	8.17	0.44	3.12	1.74	86.53
UCV-2175	33.73	90.46	10.05	0.54	2.85	1.87	84.68
UCV-2178	32.04	90.36	9.11	0.41	3.26	1.83	85.38
UCV-2186	30.38	90.03	8.10	0.64	4.84	2.32	84.08
UCV-2194	41.73	89.63	4.15	0.51	2.93	1.61	90.78
UCV-2062	31.65	89.13	4.92	0.49	2.74	1.77	90.16
UCV-2106	37.04	90.40	6.50	0.48	3.24	1.43	88.33
UCV-2110	35.02	90.50	6.93	0.47	2.65	2.54	87.41
UCV-2105	30.51	89.87	8.33	0.67	5.51	2.77	82.71
UCV-2112	33.09	89.53	3.93	0.53	2.39	1.63	91.51
UCV-2137	33.96	89.67	5.87	0.47	2.89	1.88	88.87
UCV-2196	31.40	89.77	7.57	0.52	3.06	2.41	86.42

[1]Analyses of whole reserve roots from plants 10-months-old, not fertilized or treated with any chemicals (values are means for 3 samples). Analysis by J. Perdomo, Facultad de Ciencias Veterinarias, Universidad Central de Venezuela, Maracay.

Han Kwo (1968), and Barrios and Bressani (1967).

The crude fibre levels reported are lower than those found by Barrios and Bressani (1967); whereas, the levels of the ether extract and the percentage ash content are lower.

The first five clones listed in Table 5 are bitter in taste, the rest are sweet. There was no clear association between bitterness and high protein content.

Amino Acids

The amino acid levels of cassava root are given in Table 6 (Maner 1973). The levels of lysine and tryptophan are high in the true pro-

Table 6. Amino acid analysis of roots of Llanera variety of cassava (mean of 2 samples).

	Percentage of crude protein	Percentage of true protein
Arginine	15.00	38.30
Histidine	0.56	1.50
Isoleucine	0.90	2.27
Leucine	1.38	3.44
Lysine	1.55	3.88
Methionine	0.33[1]	0.82[1]
Cystine	0.25	0.63
Threonine	0.93	2.33
Phenylalanine	0.86	2.12
Valine	1.27	3.18
Tryptophan	0.50	1.26

[1]Based on only 1 sample.

tein fraction, the levels of methionine and cystine are low.

Minerals

Barrios and Bressani (1967) reported that under dry conditions the mineral content of cassava root bark is higher than that of the central cylinder. Calcium values in the whole root range from 15 to 129 mg/100 g, P values are constant throughout the root at about 100 mg/100 g. The content of Fe varies from 32 mg/100 g in the central cylinder to 77 mg/100 g in the bark. Lira and Fernandes (1964) report high values for some minerals in cassava flour from the Amazon region: up to 100 mg/100 g Ca; 71 mg/100 g P; but only 6.5 mg/100 g Fe.

Fats

According to Hudson and Ogunsua (1974) cassava flour contains about 2.5% lipids, about half of which are extractable with conventional solvents. The extractable lipids were mainly polar, the principal group being galactosyl diglycerides, and a new lipid, tetragalactosyl diglyceride was described. The component fatty acids were relatively saturated compared with the structural lipids of the potato.

Vitamins

Maravalhas (1964a,b), studying the carotenoids in the root of yellow fleshed cassava varieties from the Amazon basin, found that 100 g of fresh material contained: 1.35 mg α-carotene; 0.50 mg β-carotene; and 0.50 mg hydroxycarotene. These carotenoids are not lost in the preparation of meal from the cassava root. Riboflavin levels in fermented cassava mash were found to be 0.03 mg/100 g by Ankrah (1972). The preparation of meal did not significantly alter this level. Rojas (1968) determined the vitamin C content of the roots of six cassava clones from Peru: for raw samples the values were 38.5–64.6 mg; for fried samples 29.1–47.8 mg; for boiled samples 21.5–40.6 mg; and for dry roots 2.8–13.0 mg. Raymond and Jojo (1941) reported values of 2000 mg of vitamin C per 100 g of cassava leaves following an extraction and vacuum concentration of the juices.

HCN

Marcano (1965), working with Venezuelan varieties found HCN levels of 167–260 mg/kg of fresh root. Gondwe (1974) reported HCN levels (mg/kg) of fresh products as: 568–620 in young leaves; 400–530 in mature leaves; 608–950 in root bark; and 45–330 in the pulp.

The enzyme rhodanase is responsible for the reaction of HCN with thiosulfate or colloidal sulfur under aerobic conditions to produce the detoxification product, thiocyanate (Oke 1973a). Vitamin B_{12} can react with cyanide to produce another means of detoxification. Cystine reacts with cyanide to form cysteine and other compounds that are excreted. Studies on the chronic toxicity of cassava and/or added cyanide have been performed by Maner and Gómez (1973) with rats and pigs. Methionine supplementation significantly improved body growth and feed conversion of animals fed cassava-based diets, and led to an increase in urinary excretion of thiocyanate. The improvement of protein quality and the utilization of methionine-sulfur in the detoxification processes appear to be the main reasons for the response to methionine supplementations.

Sinha et al. (1970) studied the effect of the application of N (urea) on the HCN content of cassava roots. Foliar spray application of urea reduced the HCN content by 55–67% compared with soil application. The application of half to the soil and half to the foliage gave a decrease of 23–50% in HCN content.

Diseases and Pests of Flours and Foliage

Nagarajan et al. (1973) reported a blue fluorescent compound from fungus-infected cassava chips that was not aflatoxin. However,

the importance of screening for aflatoxin must be stressed. Schmidt (1966) in an analysis of 50 cassava food products found a high level of bacteria and fungi. Half of the samples contained more than 18 million bacteria per gram. Almost one-third of the samples contained a high level of fungi (over 100 000/g) and approximately one-quarter of the meal and chips contained more than 200 000 fungi/g. *Aspergillus flavus*, *A. fumigatus*, *A. chevaliere*, *A. terreus*, and *Penicillium rubrum* were found. The author concluded that the high microorganism content of many of the cassava food products could make them harmful for consumption.

Studies made by Pillai (1976) in India revealed cassava chips of two varieties were significantly superior to all other varieties tested in their resistance to the storage pest *Araeceras fasciculatus*. Dry cassava products such as flours or pellets kept for 3–6 months without suffering damage. Dry cassava products have a moisture content of 10–12%, and for storage it is not economically feasible to reduce this further because of the prevailing climatic conditions in tropical countries. Ingram and Humphries (1972) quoting different authors, advise treatment with methyl bromide, ethylene dibromide, or a mixture of dibromide methyl and carbon tetrachloride to control pests in dry cassava products.

Silage

Serres and Tillon (1972) prepared cassava root silage in a cylindrical cement vat, in a ditch covered with plastic, and in a metal vat. The silage prepared in the cement vat was acceptable when fed to cattle and swine. In Colombia (Instituto de Investigaciones Tecnologicas 1975) tests have been made with field clamps and boxes with moist sawdust with satisfactory results.

Refuse

Greenstreet and Lambourne (1933) advise the use of cassava refuse for the extraction of starch for feeding pigs. Cassava waste on a fresh basis contains: 23.3% starch; 0.5% crude protein; 2.2% crude fibre; and 0.4% ash. On a dry basis it contains 88.3% starch; 1.9% crude protein; 8.3% crude fibre; and 1.5% ash. This product can be used fresh if an animal farm is close by; or if a dehydrator is used in the main plant, the product can be dried and used as a filler in composite feed.

Cassava Foliage as Animal Feed

The aerial part of the cassava plant is composed of stems, branches, and leaves. The stake that is planted gives rise, at its apical end, to one or more stems. Each stem, some 40–50 cm from the soil becomes branched (usually three times). The stem has a bark and a central cylinder. The leaves are alternate, simple, and have a short life of 1–2 months. The mean size of the leaves is 14–17 cm; the petioles are long and thin (20–40 cm). In 4-month-old plants (11 clones) the mean proportion of the different parts was: stems and branches 42%; leaf blades 36%; and leaf stalks and petioles 22%. In adult plants (12-months-old) the proportions were: stems and branches 81%; leaf blades 7%; and leaf stalks 12%. Bangham (1950), Echandi (1952), Juárez (1955), and Miranda et al. (1957) were among the first to suggest the possible value of cassava leaves for animal feed. The main products supplied by cassava foliage (leaves and stems) are: protein, carbohydrates, and vitamins.

If cassava leaves are to be used for feeding animals it is essential that mechanical harvesting devices be developed that are able to harvest different parts of the foliage from 4 months age in a cycle of 60–75 days. Cassava plants are able to support this treatment for several years (Fig. 1), provided they are adequately irrigated and fertilized.

Protein

The protein content of cassava leaves and foliage compared with other plants is given in Table 7. Echandi (1952) compared the protein content of cassava foliage meal (leaves and stems) with alfalfa and found the percentages of crude protein to be 16.9 and 17.0, respectively. The cassava was judged to be superior because it had less fibre and higher concentrations of fat and carbohydrate. In feeding trials with milk cows, the cassava meal proved to be economically superior under tropical conditions.

Juárez (1955) investigated the root and leaf production of 16 cassava varieties and found that when the leaves were cut at 7 months there was a decrease in root yield at harvest (11.5 months). The total yield of leaves could be increased by cutting at 7 and 11.5 months. The protein content of the leaves of two varieties was 15.8 and 20.3%, compared with

Fig. 1. With adequate irrigation and fertilization cassava plants are able to support foliage harvesting for several years.

20.3% for alfalfa (dry weight basis). Paula (1952) and Paula and Cavalcanti (1952) after analyzing the amino acid content of cassava leaves emphasized the value of this product as an animal feed. Valor das Folhas (1968) recommended the use of cassava leaves for feeding laying hens.

Adrián et al. (1969) recorded the serious methionine deficiency in the amino acid profile of cassava, and mentioned that the industrial extraction of cassava leaf protein is difficult because the nitrogen fraction is only soluble at pH 12. However, it should be remembered that when cassava foliage is fed as meal there is no need for an expensive industrial extraction process.

Gramacho (1973) found that cassava leaf blades were very high in protein (30.5%), compared with a value for the whole foliage of 13.0%. Velloso et al. (1967) conducted feeding trials with cassava, alfalfa, soybean, and capim pangola. In the trials, alfalfa was replaced by the other tropical plants in swine rations at a level of 5% of the total ration. No significant differences were found among the treatments or between the sexes.

Van Veen (1938) pointed out the importance of cassava leaf consumption as a supplement to carbohydrates in root diets. He concluded that cassava had as good a supplementary value as rice protein, but that it was slightly inferior to soybean protein.

Pirie (1960), based on experiments with rats, chickens, and pigs, concluded that the value of isolated plant protein was as good as or higher than fish protein. Montilla (1976) reported the proximal analysis of 11 composite samples of cassava foliage on a dry matter basis: crude protein 21.7%, ether extract 3.7%, crude fibre 19.5%, NFE 44.6%, and ash 10.5%. At CIAT (1973) trials of different planting densities (110 000 vs. 28 000 plants/ha) on the production of cassava foliage consistently gave the highest yield of dry matter and protein with the closer planting density.

In general, the protein content of dry cassava leaves averages 25%; when the entire foliar part of the plant is used this value is 17.2%. This is comparable with alfalfa hay (17.4%); however, cassava gives a much higher yield per hectare, and alfalfa is hardly adapted to the type of ecological conditions

Table 7. Crude protein content (%) and crude fibre content (%) of cassava leaves and foliage compared with other plants (authors as indicated).[1]

	C.P. (%)	C.F. (%)
Fresh Leaves		
Cassava (mean) (1, 12, 13)	7.1	1.4
Desmodium barbatum (2)	7.8	13.7
Stylosanthes ingrata (2)	4.4	6.8
Pueraria phaseoloides (2)	4.3	8.4
Dry Leaves		
Cassava (mean) (1, 4, 6–8, 11, 12)	25.0	13.3
Dry Foliage		
Cassava (mean) (3–7, 9, 10, 14)	17.2	23.5
Desmodium barbatum (2)	8.5	29.5
Stylosanthes ingrata (2)	17.6	21.7
Pueraria phaseoloides (2)	4.0	23.8
Stylosanthes gracilis (8)	14.0	35.0
Pennisetum purpureum (8)	11.0	36.0
Panicum maximum (8)	7.0	38.0
Brachiara brizantha (8)	10.0	27.0
Digitaria decumbens (14)	10.8	34.4
Medicago sativa (mean) (4–7, 14)	17.2	30.4

[1](1) Barrios and Bressani 1967; (2) Bermudez 1973; (3) CIAT 1973; (4) Conceicao et al. 1973; (5) Echandi 1952; (6) FAO 1975; (7) Gramacho 1973; (8) Lim Han Kwo 1968; (9) Montaldo and Montilla 1976; (10) Montilla 1976; (11) Pechnik et al. 1962; (12) Rogers and Milner 1963; (13) van Veen 1938; and (14) Wu Leung and Flores 1961.

where cassava grows. The crude protein content of cassava is higher than most tropical plants growing under the same conditions.

Amino Acids

Pechnik et al. (1962) determined the amino acid content of cassava leaves as follows: essential — arginine, histidine, leucine and/or phenylalanine, methionine and/or valine, tryptophan, and threonine; nonessential — aspartic acid, alanine, cystine, glycine, glutamic acid, hydroxiproline, proline, serine, and tyrosine.

Eggum, working on the biological evaluation of cassava leaf protein in rats, found that the true protein digestibility was 70–75%, and that the biological value ranged from 49 to 57%. Although the net protein utilization is low, Eggum (1968) states that because of the high N content of the leaves, the utilizable N is twice that of cereals. Eggum (1970) supplied N requirements by: (1) half cassava leaf meal and half dry codfish; and (2) cassava leaf meal supplemented with synthetic methionine. Dry codfish contains a higher quantity of all essential amino acids, including methionine, and certainly the biological value of its protein is superior (78% vs. 48% for cassava leaf protein). When these two protein sources were combined the biological value of the protein rose to 73%. With the cassava leaf meal supplemented with methionine, the biological value was increased to 80.4%, and the utilizable N went from 2.04 to 3.20%, which is high for a foliar product. The net protein utilization, originally 36.4% for cassava leaves, increased to 58.7% when combined with dry codfish and 56.5% when supplemented with methionine.

Oke (1973b) compared the amino acid content of the leaf and root protein of cassava with the FAO essential amino acids reference pattern. Cassava leaves and roots are low in methionine with values of 1.7 and 1.2 g/100 g of crude protein compared with 2.2 for the FAO reference pattern. Lysine is high in the leaves (7.2) and low in the roots (3.9) compared with FAO (4.2). Oke suggested that the leaves could be used as a supplement to cereals in feeding.

Oke also extracted protein from different tropical leaves and found that of the seven tropical feeds compared, cassava had the second highest value of weight of N extracted, and also the second highest value for percentage of N extracted. The combination of these values makes cassava leaves a good source of crude protein.

Müller et al. (1974) reported the amino acid content of cassava foliage and found it to be similar to grains and legumes (Table 8). Their results showed a tendency of higher values for essential amino acids in the foliage of cassava, except for arginine and leucine.

Singh (1964) studied the leaf protein extraction of 38 cultivated species. Total nitrogen and protein nitrogen were determined. Samples of crude protein were also prepared and analyzed for nitrogen content. Protein extraction from the leaves was low as shown by the values of extractable N as a percentage of total N in the leaves of 10.0 for cassava and 55.4 for alfalfa, and the values for extractable protein nitrogen as a percentage of total N in the leaves of 5.0 for cassava and 42.2 for alfalfa. Even considering these low levels of extraction of N from cassava leaves, the work by Eggum in supplementing root meal with methionine to raise the biological value from 48.9 to 80.4 shows that low solubility is not a

Table 8. Amino acid levels (%) of cassava foliage compared with some other tropical feedstuffs (Müller et al. 1974).

	Cassava		Elephant grass	Guinea corn	Soybean
	Leaves	Foliage			
Crude protein	27.0	20.3	12.6	11.9	45.7
Arginine[1]	5.21	3.89	6.10	5.64	7.41
Cystine	1.18	0.98	0.51	—	1.52
Glycine	4.92	5.10	5.85	5.00	5.23
Histidine[1]	2.47	2.32	2.54	2.82	2.39
Isoleucine	4.12	4.40	4.32	3.45	5.45
Leucine[1]	10.00	8.75	8.64	7.55	6.97
Lysine	7.11	5.89	6.02	4.82	6.32
Methionine[1]	1.45	1.83	1.86	1.36	1.52
Phenylalanine[1]	3.87	4.37	5.42	5.82	4.79
Threonine[1]	4.70	5.70	4.41	4.73	4.14
Tryptophan	1.09	1.24	—	—	1.30
Tyrosine	3.97	4.12	3.73	3.18	3.27
Valine	6.18	8.43	6.27	5.18	5.23

[1]Essential amino acid.

problem for monogastric animals. The yields of cassava meal/ha/month and of alfalfa under tropical conditions also influence the economic utilization of these food crops.

Adrian and Peyrot (1971) compared the amino acid content of cassava leaves with whole egg. The cassava proteins were found to have a serious deficiency of methionine (−67% compared with egg, 1.20 vs. 3.65 g/100 g), but a rather satisfactory balance of the other essential amino acids. Cassava leaf protein therefore cannot improve the quality of a diet limited by methionine, but can be useful in the case of cereal diets that are lysine deficient (wheat, sorghum, millet, etc.) or are lysine-tryptophan deficient (maize).

Peyrot (1969) analyzed the leaves of different green crops in the tropics, including *Dioscorea alata*, *Adamsonia digitata*, *Ceiba pentrandra*, and *Manihot esculenta*, and concluded that all were deficient in methionine. Cassava was the only one recommended for use in the preparation of supplemental rations for animal feeds.

Luyken et al. (1966) showed that tryptophan, methionine, and cystine levels are low in cassava leaves, and that the biological value of the leaves as determined with rats, was low, although the addition of methionine improved this condition. At IITA (1974) the protein content of cassava leaves on a dry weight basis was determined in 181 clones, and was found to range from 26 to 42%. The 12 clones with the highest protein content (40–42%) were analyzed for lysine (3.49–4.21) and tryptophan (0.63–0.95). Compared with the FAO amino acid reference pattern, the values for tryptophan were low, and those for lysine were about the same. The values for lysine are low compared with the value of 7.2 given by Oke (1973b).

The biological value of cassava foliage is very variable and is inferior to that of animal protein. However, these deficiencies can be overcome by mixing the cassava with other protein sources such as: (1) animal protein; (2) a synthetic amino acid; (3) other plant proteins, e.g. sesame (*Sesamum indicum*) and cotton (*Gossipium hirsutum*) that are high in methionine and are readily available in tropical markets.

To produce cassava foliage protein the leaves can be dried either in the sun or with a dehydrator. Industrial protein extraction is expensive and requires a special factory and machinery. However, our experience has been that we can dry the foliage in the sun in 2 days by chopping it with a mill and spreading it on a concrete floor at a density of 15 kg/m^2. The first day the chopped leaves have to be moved every 2 h, the second day they only have to be moved twice.

Carbohydrates

The results of carbohydrate analyses of leaf and foliage meal have given erratic results. For more consistent results researchers must

define the purpose of the sample, agree upon sampling methods, and standardize analytical methods.

For preparing cassava foliage meal it appears that the best conditions are to take samples from 60–75-days-old plants that have new developing foliage. The final sample should be expressed on the basis of 10–12% humidity because the material to be replaced in the diet (usually maize or sorghum) is normally found at this level of moisture.

The average values obtained for carbohydrates were: fresh leaves 11.4% (Barrios and Bressani 1967); dry leaves 46.5% (Barrios and Bressani 1967; FAO 1975; Gramacho 1973); and dry foliage 43.5% (Echandi 1952; Gramacho 1973; Velloso et al. 1967). Most of these carbohydrates are starch. Based on a study of 245 clones at IITA the amylose content was observed to be in the range 19–24%.

Crude Fibre

Table 7 gives values for the crude fibre of cassava and various other plants. The crude fibre content of fresh cassava leaves is low compared with the other species listed, as well the crude fibre level in the dry foliage is low compared with other tropical forage crops.

Minerals

Both fresh and dry cassava leaves are high in Ca but low in P compared with maize and sorghum. Pechnik et al. (1962) compared raw leaf cassava flour with boiled leaf cassava flour and obtained the following values: 1120 and 1070 mg% Ca; 300 and 250 mg% P; 31 and 30 mg% Fe; and 1080 and 834 micrograms%, respectively.

Vitamins

Vitamin levels for 100 g of fresh cassava leaves are given in Table 9. It can be seen that the values given by the different authors are quite similar. In any case, vitamins need not be a problem in animal feeding because they are readily available in synthetic and highly concentrated forms at reasonable cost. Seagram, quoted by Conceicao et al. (1973), gave values for vitamin A of 56 000 IU in cassava foliage meal, 14 200 IU in alfalfa meal, 660 IU in ground yellow maize, and 264 IU in wheat flour. Bangham (1950) also gave a value for dry cassava leaves of 65 000 IU. This high amount of vitamin A in cassava foliage meal appears to be important for the pigmentation of egg yolks.

Pechnik et al. (1962) comparing raw and cooked cassava leaf flour at 5% humidity found the following: carotene 25 and 24 mg% and total nicotinic acid 0 and 7 mg%, respectively.

Table 9. Vitamin levels for 100 g of fresh cassava leaves.

	Terra 1964	Wu Leung and Flores 1961	van Veen 1938
Vitamin A	30000 IU	10000 IU	14500 IU
B_1 Thiamine	0.12 mg	0.14 mg	100 IU
B_2 Riboflavin	0.27 mg	0.26 mg	0.43 mg
Niacin	1.70 mg	1.50 mg	—
Ascorbic acid	290 mg	300 mg	165 mg

Table 10. Distribution of glucoside (mg HCN/g fresh weight) and of linamarinase (mg HCN liberated/g fresh weight/min) in different parts of the cassava plant (average of four clones).

	Glucoside	Linamarinase
Leaf blades		
very young (in expansion)	490	730
just full grown	590	300
older	380	100
Leaf stalks		
very young (in expansion)	720	740
just full grown	340	360
older	150	380
Stem bark		
near oldest leaves	630	150
at 2/3 of leafless part	310	90
at 1/3 of leafless part	420	80
lowest part	780	6
Bark cutting	440	35
bark of reserve roots	640	270
inner part of reserve roots	140	9

HCN

De Bruijn (1973) has established the distribution of both the glucoside that is generated by the enzymatic hydrolysis of HCN and also of the enzyme linamarinase (Table 10). There is a high amount of glucoside in the older leaves compared with the proportion of lina-

marinase; whereas, in the leaf stalks the levels of HCN and the enzyme are almost equal. The stem bark is higher in HCN than the enzyme, but this may not be important if fresh material obtained from periodic cuts is used. The bark of the reserve root (important for its crude protein content) is also high in HCN and low in linamarinase. It therefore seems advisable to combine very young leaves (high in linamarinase) with the bark of the reserve root (high in the glucoside) to accelerate the process of HCN liberation. The proportion of these elements in the mixture is yet to be determined.

Pechnik et al. (1962) determined that the level of HCN in raw cassava leaf meal was 23 mg% and that in cooked cassava leaf meal the level was 0.9 mg%. Montilla et al. (1976) conducted a series of tests, at 24-h intervals, to determine the rate of liberation of HCN from both the foliage and the reserve root. These tests also investigated the rate of liberation from a 1:1 mixture of roots and foliage on both a fresh weight and dry weight basis. The results indicated that the liberation of HCN is higher in the foliage, as was also shown by de Bruijn, and that the combination of roots with foliage acted in a manner very similar to the foliage.

These findings are of significance in the dry topics because they provide a method of reducing the HCN content of cassava-based animal feeds that does not require the addition of water.

Economics of Cassava Foliage Production

Scholz (1972) obtained 3 t of dry cassava leaves (10–12% protein) by pruning the plants at 9 months and by harvesting the roots at 12–13 months. Ismail, cited by Mahendranathan (1971), obtained a fresh cassava leaf harvest of 6.7 t/ha over a 12.5 month period with periodical cutting. Meyreles and Macleod (1976) planted cassava at different densities to produce foliage as a protein source for animal feeding. They concluded that the best density was 60 000 plants/ha, and that the foliage should be cut from the age of 3 months every 3 months. The mean protein content at 3 months was 15.7%. Using a density of 31 250 plants/ha, Montaldo and Montilla (1976) cut all the foliage at 3, 6, 9, 12, 14, and 17 months and obtained 31.86 t of dry foliage (18.2% crude protein), which represents a crude protein production of 5.8 t/ha over 17 months. Using a mean of 43.5% carbohydrate, this represents the production of 13.8 t of total carbohydrate in addition to vitamins, minerals, fats, etc.

Cost of Production of Cassava Foliage in Venezuela

In Venezuela, cassava foliage production costs are $1417 per hectare ($80 for mechanical land preparation, $419 for planting, $54 for cultivation, and $864 for harvesting and processing) or $44 per tonne of dried foliage, which contains 182 kg of crude protein and 435 kg of carbohydrate. In contrast in March 1977 in Venezuela 1 t of dried alfalfa meal containing 174 kg crude protein and 292 kg of carbohydrate sold at $224 or about five times the price of dried cassava foliage on a protein equivalent basis.

This shows the great advantage of using cassava leaf protein rather than alfalfa leaf protein for animal feeding in the tropics. The large difference in costs of production allows the addition of methionine, animal protein such as blood flour, or cotton or sesame cakes to the rations to improve their biological value.

Expansion of Cassava Root and Foliage Production

Many studies of cassava production for the future only consider the necessity to keep pace with the increases in consumption due to human population growth and demands for pellets by the EEC for animal feeding (Phillips 1974). However, the population in the tropics — 2.3 billion people — also must improve their diets by increasing their protein consumption (Ehrlich and Ehrlich 1970).

A very positive step could be taken if we could give the tropical peoples an additional 6 kg of poultry meat, 5 kg of swine meat, and 200 eggs — three times their present yearly consumption, but still only half of the consumption in the developed countries.

To produce 6 kg of poultry meat 19.8 kg of feed are required (conversion 2.7); 5 kg of swine meat require 27.0 kg of feed (conversion 3.8); and 200 eggs require 36.7 kg of feed (conversion 2.2/dozen eggs).

If 70% of this feed was provided by cassava (50% from root production (10 t/ha) and 20% from foliage meal production (25 t/ha), 192 million tonnes of cassava products would

be required. For the 50% made up of cassava root meal the area required for production would be 9.6 million hectares; for the 20% from cassava foliage meal the area required would be 1.5 million hectares. The total area that would be required would be 11.1 million hectares, which could be made available without replacing other food crops. In comparison, if this feed was produced with cereals (maize, sorghum, millet, and rice) and oil plants (peanuts, sesame, and cotton) it would require 190 million hectares of good soil.

Cassava as a Feed Source for Ruminants

C. Devendra[1]

Present knowledge concerning cassava as a feed source for ruminants with respect to type of feeds from the cassava plant, nutritive value, utilization of leaves, stems, and tubers, pattern of starch digestion, utilization of nitrogen, and HCN toxicity is reviewed. Only limited information currently exists concerning cassava in ruminant feeding, and several pertinent areas for research exist.

The approximate proportions of principal products and by-products of the cassava plant at maturity are 6% leaves, 44% stems, and 50% tubers. The latter is made up of 8% peelings, 11% water, 31% starch, and pomace, a by-product of starch manufacture, contributes 17% (chemical composition is reported). The crude protein content of the leaves is relatively high, but they have been inadequately used as a protein source. A 25% level of cassava forage (leaves + stems) with 75% grass appears to be promising. Tubers can be substituted for cereals or other carbohydrate energy sources without any loss in performance, especially of dairy and beef cattle, with attendant feed cost reductions. The potential to increase the use of tubers and leaves to supply energy and protein requirements, and possibly use leaves and stems as forage, is quite enormous.

Both balance and feeding trials indicate that about 20–30% dietary levels of cassava chips are most efficiently utilized. Higher levels, while supplying increased energy, are less well utilized due to reduced digestibility, probably because of reduced amylolytic activity in the intestinal tract posterior to the rumen. In rice straw-molasses diets with cassava chips, maximum N retention occurred when urea supplied 62–63% of the total crude protein requirements. Supplemental DL-methionine significantly improved crude fibre digestibility, suggesting that it may be important in stimulating the activity of cellulolytic rumen bacteria. Very little is known about the effect of cassava feeding on HCN toxicity and other deleterious effects in ruminants.

Deficiencies in our knowledge justify research in the following areas: feeding value of leaves, stems, and tubers; digestion in the rumen and the intestinal tract; effect of processing including carbohydrate structure; cyanogenic glucosides; and development of appropriate feeding systems and technologies suited to cassava utilization by the ruminant.

One feature of the productivity of ruminants in the tropics is their inherent low level of performance, which is invariably associated with substandard nutritional management and inadequate exploitation of the attributes of the individual species, such that their potential productivity is often never realized.

This low productivity is dependent primarily on the availability, particularly, of energy and protein. Both components are invariably the major constraints to increasing productivity from ruminants in the tropics. In some countries, such as those in the Caribbean, energy rather than protein is the main limiting factor; whereas, in others such as those in Southeast Asia, the reverse is true. Often, both nutrients are limiting and the situation becomes even more acute when the need for, and dependence on them is accentuated by the use of traditional sources of energy, notably maize. The situation is often compelling enough to explore other local sources of energy, notably carbohydrates and to a lesser extent fats for ruminant feeding.

This approach has led to an examination of the availability and potential value of energy yielding feedstuffs in several countries in the tropics. Perhaps the most significant demonstration of this approach concerns sugarcane and its by-products (Preston and Willis 1969; Preston 1974). Similarly, consideration is also being directed at other high energy feedstuffs to alleviate the low level of nutrition, and therefore performance, of tropical ruminants.

Notable among the potentially very useful energy feedstuffs is cassava (*Manihot esculenta*), a traditional subsistence crop of low-income families in the humid tropics, and probably the most important root crop for feeding humans and domestic animals. It is bulky, high in energy, low in protein, and produces relatively high yields per unit area of land; therefore, it represents an important supply of energy for feeding livestock. Conse-

[1]Malaysian Agricultural Research and Development Institute, Serdang, Selangor, Malaysia.

quently, it is becoming increasingly recognized as an attractive substitute to traditional energy sources like maize. In Venezuela, for example, cassava is favoured over maize or wheat because of its yield, and agronomic and nutritive characteristics (Ferrer 1970). Some idea of the relative yield of cassava compared with other energy sources in Malaysia is given by the following yield data (ME[2] on a dry matter basis): cassava 25 tonnes/ha, 23.9 MJ/ha; maize 3.4 tonnes/ha, 9.9 MJ/ha; rice 2.5 tonnes/ha, 7.3 MJ/ha; sago 20.9 tonnes/ha. 12.0 MJ/ha; sorghum 4.5 tonnes/ha, 12.4 MJ/ha; sweet potato 12.5 tonnes/ha, 14.3 MJ/ha; whole sugarcane (derinded stalk) 69.2 tonnes/ha, 71.2 MJ/ha; and final molasses 2.8 tonnes/ha, 4.9 MJ/ha.

Although cassava has been used in diets for livestock, the efforts have been mainly directed at nonruminants, and there is a considerable amount of data on utilization by pigs (Modebe 1963; Devendra 1963; Maner 1972; Maust et al. 1972a; Tillon and Serres 1973; Hew Voon Fong 1975), and poultry (Klein and Von Barlowen 1954; Yoshida 1970; Hutagalung et al. 1973; Müller et al. 1974a; Syed Ali and Yeong 1976).

By comparison, the situation regarding utilization of cassava by ruminants is scanty, probably for four reasons: (1) the traditional view that the high energy, low protein, and low fibre content of cassava make it more suited for feeding to nonruminants; (2) the traditional dependence on maize as the main energy source; (3) the presence of hydrocyanic acid (HCN) and problems of toxicity; and (4) its value for human consumption.

Additionally, only recently has consideration been given to the potential feeding value of other parts of the cassava plant (leaves and stems) in the diets of ruminants. This review attempts to bring together the information currently available concerning all aspects (roots, stems, and leaves) of cassava as a feed source for ruminants.

The principal products and by-products of the mature cassava plant (12 months), expressed as a percentage of the whole plant, that can be exploited for animal feeding are: leaves 6%; stems 44%; and tubers 50% (comprised of 11% water, 8% peelings, and 31% starch). The stems and leaves are by-products of tuber harvesting; whereas, pomace (about 17% of the whole plant) is a by-product of starch manufacturing and has an extraction rate of 55–57% (Devendra 1976a). These values are only approximate and it is emphasized that they vary with the rate of production and also are influenced by climate, soil type, age at harvest, and fertilization.

A variety having a larger proportion of tubers would suggest its superiority for use in human nutrition; whereas, if the proportion of stems to tubers is approximately equal this reflects a lower tuber yielding variety.

Nutritive Value

The proximate composition of the cassava plant (Table 1) indicates that the roots are a concentrated source of energy. Of significance is the fact that the leaves have a relatively high content of crude protein, and that the stems have approximately half this content. The former compare with crude protein contents of 15–30% in Brazil (Pereira 1966; Silva 1966); 25.5% in Florida (Ramos-Ledon and Popenoe 1970), 27.0% in Singapore (Müller et al. 1974a,b), 22.3% in Sri Lanka (Siriwardene and Ranaweera 1974), and 28.0% from Colombia (Moore 1976). The crude protein content of the stem (10.9%) is comparable to the value of 11.3% reported from Colombia (Moore 1976). Of the main products, the stems, understandably, have the highest crude fibre content (approximately 23.0%), comparable with 22.0% reported by Moore (1976).

The nutritive value of cassava roots has been reported by French (1937) and Oyenuga (1955) in Africa; Maner (1972) in Colombia; Müller et al. (1974b) in Singapore, and Hew Voon Fong (1975) in Malaysia. Mudgal and Sampath (1972) have reported that the nutritive value of cassava was 1.46 DCP and 83.3 kg TDN/100 kg dry matter. In view of the relatively high content of crude protein in the leaves (23.2%) it is relevant to consider the nature of their amino acid profile (expressed as grams/16 grams N): arginine 5.1; cystine 1.0; glycine 4.6; histidine 2.7; isoleucine 4.3; leucine 4.7; lysine 7.1; methionine 1.1; phenylalanine 3.6; threonine 4.7; tryptophan 1.0; tyrosine 3.2; and valine 6.4.

The amino acid profile is similar to that reported by Müller et al. (1974b) and Hutagalung et al. (1974). The sulfur-containing amino acids, cystine and methionine, are low

[2]1 MJ = 238.89 kcal.

Table 1. Chemical composition of feed from a mature cassava plant (% dry matter basis).

	Leaves	Stems	Roots[1]	Peelings	Pomace
Crude protein	23.2	10.9	1.7	4.8	1.8
Crude fibre	21.9	22.6	3.2	21.2	24.2
Ether extract	4.8	9.7	0.8	1.2	0.4
Ash	7.8	8.9	2.2	4.2	3.4
Nitrogen-free extract	42.2	47.9	92.1	68.6	70.2
Ca	0.972	0.312	0.091	0.312	0.712
P	0.576	0.341	0.121	0.127	0.112
Mg	0.451	0.452	0.012	0.215	0.219
Gross energy (MJ/kg)	2.59	2.67	15.6	2.96	2.39

[1]Includes peelings (referred to as chips).

in relation to the other amino acids, which Rogers and Milner (1963) have also noted. Methionine could therefore easily be limiting if the amount naturally present is associated with the detoxification of hydrocyanic acid (HCN).

Utilization of Leaves

Of the cassava feed products of value to the ruminant, the leaves are probably the least exploited, despite their relatively high crude protein content. The main reason for this is probably associated with the recognition, and indeed use in Africa and parts of Southeast Asia, of the leaves as a protein source for humans (Terra 1964). Considerable effort has been directed at extracting proteins from the leaves; however, limited progress has been made because of the high cost of extraction.

Few reports exist on the value of feeding cassava leaves to ruminants, but they have been used for feeding calves in France (Guin and Andouard 1910) and cattle in Cuba (Osvaldo 1966). In Madagascar, Seeres (1969) reported the use of the leaves to fatten lean Zebu cattle; very fat carcasses were reported. In Brazil, leaves are considered valuable as a forage especially in the dry season when feeds are scarce (Gramacho 1973). The lack of interest in the use of cassava leaves to feed ruminants is related to: (1) decreased root yields due to harvesting the leaves (Mohd. Ismail Ahmad 1973); (2) relatively low yields during harvesting at maturity; (3) possibilities of HCN toxicity, especially with bitter varieties; and (4) inadequate appreciation of the relatively high crude protein content of the leaves.

It is interesting to note that fresh leaves are commonly fed directly to ruminants after sun drying. This is believed to reduce the level of HCN in the leaves by interaction with the sun's heat. This point, however, is not entirely supported by HCN levels (mg/kg) recorded after sun drying fresh leaves (Black twig): fresh variety 235; after 2 h 470; 4 h 475; 6 h 470; 8 h 445; 10 h 324; and after 24 h (oven drying at 36 °C) 120. The effectiveness of 36 °C in reducing the HCN content is in agreement with the reports of Charavanapavan (1944) and Joachim and Panadittsekers (1944). The reason for the higher values may be due to prevention of autolytic hydrolysis of the glucosides consequent to elevated temperatures, and possibly also due to the fact the leaves were not mechanically damaged. Recently, a technique has been developed in Sri Lanka to reduce the HCN content by drying the leaves (Siriwardene and Ranaweera 1974) for feeding purposes. In view of their relatively high content of crude protein, the importance of cassava leaves as forage and as a protein source for ruminants needs to be recognized in situations where protein is the main factor limiting improved animal production.

Although evidence for the direct utilization of cassava leaves by ruminants appears to be scarce, by comparison, attention has been given to feeding the foliage (leaves + stalks). In Costa Rica, Echandi (1952) showed the foliage to be as good as alfalfa meal. Grazing milk cows given the meal gave 90–96% as much milk as those receiving equal amounts of alfalfa meal, and because the latter was imported, the economic value of the cassava is obvious. Meal made from leaves and stalks was considered suitable for animal feeding in Brazil (Normanha 1962).

More recently, detailed studies have been conducted in Colombia on the feeding value of

Table 2. The effect of feeding elephant grass supplemented with cassava foliage[1] (Moore 1976).

	100% grass	75% grass + 25% cassava foliage	50% grass + 50% cassava foliage
Initial live weight (kg)	265.5	276.3	270.0
Final live weight (kg)	342.5	392.7	379.0
Daily LW gain (g)	306.0	461.0	445.0
DMI/day (kg)	5.4	6.3	6.1
Feed efficiency	17.6	13.7	13.7

[1]Refers to leaves plus stems.

the foliage for ruminants (Moore 1976). The evaluation involved feeding steers weighing 250 kg live weight one of three treatments: (1) feeding elephant grass alone (*Pennisetum purpureum*); (2) 75% elephant grass + 25% cassava foliage; and (3) 50% elephant grass + 50% cassava forage. The results are summarized in Table 2.

Treatment two (75% elephant grass + 25% cassava foliage) with a crude protein content of 9.7% gave the highest daily live weight gain compared with all grass (with 6.0% crude protein) and the 50% grass + 50% cassava foliage (with 13.0% crude protein). The results suggest the adequacy of a 9.7% crude protein content, and that feed efficiency was improved by the inclusion of cassava foliage. Moore (1976) also reported that feeding cassava foliage with chopped sugar cane was superior in daily live weight gain and feed efficiency to feeding cassava foliage plus *Desmodium distortum* having a 23% crude protein content.

Utilization of Tubers

Of the feed components of cassava, roots have the greatest value because they contain concentrated energy. Considerable attention has therefore been given to their use in diets for ruminants, especially dairy cows. Although roots have been used quite extensively to feed both dairy and beef cattle, very little use has been made of the leaves as a protein source, or of the leaves and stems as forage (Table 3).

Dairy Cattle

Lucas (1914, 1915), Mallevere (1914), Henke (1919), and Cossettes (1921) observed that cassava was of high quality for feeding dairy cows. Cassava reportedly gives butter that is firmer (Brouwer 1933), does not taint the milk (Pyanart 1951), and is efficiently utilized by dairy cows (Mandoica 1962; Albuquerque 1971). Morimoto (1950) studied the feeding value of cassava "ampas" as a substitute for beet pulp, and reported that feeding ampas resulted in greater milk and milk fat yields.

Cassava feeding (Table 3) generally increases milk yield (Cardoso et al. 1968; Olaluku et al. 1971). In dairy heifers, Pineda and Rubior (1972) reported that cassava feeding increased total live weight gain and reduced both age at first breeding and the average number of services per conception. Assis (1962) studied the effects of feeding cassava, sweet potatoes, or edible canna as a winter feed supplement to dairy cows in a switchback design, and demonstrated that cassava significantly increased milk production by 19.5% compared with 7.8% for sweet potatoes. Edible canna had no effect. The response to cassava is probably a result of the relatively higher supply of ME from cassava (11.9–14.6 MJ/kg) compared with sweet potatoes (11.0–13.4 MJ/kg) for cattle.

In view of the potential value of cassava to supply energy, several studies have reported substitution of the main energy source by cassava; these include potato flour (Pernot 1909), maize gluten (Mallevre 1914), beet pulp (Morimoto 1950), sorghum (Barrteria 1969), maize (Peixoto et al. 1955; Pineda and Rubior 1972), and oats (Mathur et al. 1969). Because in a number of these reports the response has been higher milk and fat yields and live weight gains, the results suggest that cassava represents an important source of energy in dairy cow diets, which is associated with improved performance. It is apparent therefore that very much more use can be made of cassava in those countries where it is readily available.

Beef Cattle

Several reports suggest increased live weight gains of beef cattle fed cassava (Table 3). Johnson et al. (1968) fed four groups of Angoni × Boran steers for 150 days with one of four diets based on: bran; cassava; corn and cob; or a commercial concentrate mixture. The calves fed on the commercial concentrate and cassava-based diets gained signifi-

cantly ($p < 0.01$) faster than those fed bran or corn and cob-based diets, and were similar to calves that were suckled by the dams and weaned at 7 months of age. Better performance due to cassava has also been reported by Montilla (1971) in young bulls fed with a diet containing 40% cassava meal, which gave a much better performance than maize meal. On the other hand, Soewardi et al. (1975) reported that Ongole grade heifers fed alangalang (*Imperata cylindrica*) supplemented with either maize or cassava meal, and fed at 3% metabolic body size, gave a higher biweekly live weight gain per head (7.63 vs. 3.34 kg) for maize supplementation than for cassava. In Africa, supplementing poor quality hay with cassava significantly increased the dry matter intake of Zebu cattle (Karue et al. 1973).

In Malaysia, cassava supplementation in diets for Kedah-Kelantan calves increased daily gain, feed efficiency, and age at first service compared with feeding Napier grass (*Pennisetum purpureum*) alone (Devendra and Lee Kok Choo 1975). More recently, the effect of feeding increasing levels of cassava meal (30, 40, 60, and 80%) in the concentrate fraction (25% of total dry matter intake and 75% from Napier grass) to Kedah-Kelantan heifers was studied. At 30, 40, 60, and 80% levels of cassava inclusion daily live weight gains (6–24 months) were: 318.7, 287.3, 312.9, and 281.3, respectively; whereas, the efficiencies of feed conversion (kg dry matter/kg of live weight gain) were: 12.4, 14.25, 12.90, and 14.53. Significant differences were found ($p < 0.05$) between the 30 and 80% levels for both of these parameters. The best growth rates and efficiencies of feed conversion were recorded with the 30% level of inclusion. For all treatments, correlations of mean live weight with heart girth, height at withers, body length, and hip width were highly significant ($p < 0.01$). Devendra and Lee Kok Choo (1976b) also reported improved carcass characteristics due to cassava feeding.

Cassava has also been used to replace 50 or 100% of the barley in diets for growing calves in India, and was found to improve growth performance (Mudgal and Sampath 1972). These authors also reported beneficial responses from feeding cassava to old bullocks.

The beneficial responses reported for both dairy and beef cattle suggest that as an energy source cassava can replace the cereal component of the diet. More importantly, several reports have also demonstrated that these benefits are associated with a reduced cost of feeding (Echandi 1952; Peixoto et al. 1955; Valdivieso and de Alba 1958; Cardoso et al. 1968; Mandioca 1969; Gontijo et al. 1972). Because home grown cassava is relatively cheaper than imported feedstuffs for cattle, the potential value of cassava in import substitution is quite enormous. Not enough attention has been given to developing this advantage in those areas of the tropics where there is a tradition of cassava cultivation.

Goats and Sheep

No studies have been reported concerning the value of various cassava products in the diets of goats and sheep. Cassava peelings have, however, been fed to goats and sheep in French Equatorial Africa (Walker 1951). The quantity of the peelings available to these animals was, however, probably low because, during periods of food shortages, peelings are also eaten by humans.

The addition of grated cassava to Napier grass prior to ensiling significantly increased dry matter intake, apparent digestibility of dry matter ($p < 0.01$), and N balance ($p < 0.05$) in castrated sheep in Brazil (Ferreira et al. 1974). In Venezuela, growth and metabolism studies have been conducted on West African woolless wethers (Chicco et al. 1971) involving cassava and molasses in the utilization of urea (Table 4). Cassava addition significantly increased body weight gain and bacterial protein ($p < 0.01$).

Partly in view of this deficiency, but more particularly in view of the limited work that has been reported so far on the value and manner of utilization of cassava by ruminants, a program of research was initiated to fulfill these objectives at MARDI (Devendra 1977). Five experiments in the research program, all balanced trials with sheep, are reported: trial 1, the effect of dietary cassava with rice straw in isonitrogenous diets (30% rice straw with or without 20% cassava in molasses-urea diets with 6–14% level of crude protein, 10 treatments); trial 2, the replacement of molasses by cassava with rice straw in isonitrogenous diets (20–75% levels of cassava in molasses-urea diets, isonitrogenous, 5 treatments); trial 3, the effect of increasing levels of dietary cassava (20–80% levels of cassava in molasses-urea diets, isonitrogenous, 4 treatments); trial 4, the replacement of molasses by cassava

Table 3. The effects of feeding supplementary cassava (*Manihot esculenta*) to cattle.

Type of cattle	Type of basal diet	Level of cassava inclusion (%)			Response	Reference
		Roots	Leaves	Stems		
Dairy cattle						
Calves	Potato flour[1]	—	—	—	Improved performance	Pernot (1909)
Cows	Maize gluten, peanut meal	—	—	—	Increased milk yield and live weight gain	Lucas (1914)
Cows	Maize gluten[2]	Replacement	—	—	No differences	Mallevere (1914)
Cows	Soybean cake and beet pulp[3]	76.8	—	—	Increased milk and fat yield	Morimoto (1950)
Cows	Alfalfa	—	leaves + stems	—	No differences, cassava diet cheaper	Echandi (1952)
Cows	1:1 grass:concentrate diet (cocoa pods)	—	—	—	Lower than basal diet	de Alba (1954)
Cows	Maize diet[4]	Replacement	—	—	Reduced yield compared with maize diet; reduced cost of milk production	Peixoto et al. (1955)
Calves	Copra meal, sesame oil meal, wheat bran, molasses and skim milk	10.0, 35.0	—	—	No differences	Valdivieso and de Alba (1958)
Holstein cows	Grazing[5]	Supplementary feeding	—	—	19.5% increased milk yield	Assis (1962)
Holstein and Zebu cows	Fresh and ensiled sugar cane tops[5]	0.5 kg/100 kg body weight	—	—	No differences	Estima et al (1967)
Holstein × Zebu cows	Maize diet	Up to 41.5	—	—	Milk production increased, cassava diets cheaper	Cardoso (1968)
Ayrshire × Sahiwal × Sindhi cows	Oats, gram, groundnut cake, wheat bran and gram husk[6]	12.5, 25.0	—	—	No differences; cassava diet cheaper	Mathur et al. (1969)
Cows	Ground corn	41.5	—	—	Decreased cost of milk production	Mandioca (1962)
Cows	Molasses-urea[5]	Supplementary feeding	—	—	Increased live weight gain	Neves (1969)
White Fulani cows	Hay, maize, groundnut cake, palm kernel cake	79.1	—	—	Increased milk and fat yields	Olaluku et al. (1971)
Cows	Bean fodder or pigeon pea fodder[4]	Supplementary feeding	—	—	Improved N utilization	Patel and Yamdagni (1972)
Heifers	Chopped sugar cane + limited concentrates[7]	78.5	—	—	Increased total live weight gain, reduced age at first breeding and avg. services per conception	Pineda and Rubior (1972)

(continued)

Table 3 (*concluded*)

Type of cattle	Type of basal diet	Level of cassava inclusion (%)			Response	Reference
		Roots	Leaves	Stems		
Tharparkar × Sahiwal × Sindhi calves	Barley, groundnut cake wheat bran[5]	24.0, 44.0	—	—	Improved growth	Mudgal and Sampath (1972)
Cows	Dried grass pellets[5]	8.4, 18.4	—	—	No differences	Mohme and Pfeffer (1973)
Local Indian dairy calves	Grass, copra cake, molasses-urea	8.0	—	—	Significantly affected body measurements	Devendra and Sivarajasingam (1975)
Beef cattle						
Angoni × Boran calves	Commercial concentrate	Supplementary feeding	—	—	Increased live weight gain compared with maize or bran	Johnson et al. (1968)
Nelore castrate	Rice straw, cottonseed meal[5, 8]	20.0	—	—	Increased live weight	Roverso et al. (1969)
Cows	Molasses-urea[8]	Supplementary feeding	—	—	Increased live weight gain	Neves (1969)
Criollo bulls	Maize meal, rice polishings	70.0	—	—	Improved utilization of vegetable protein	Shultz Shultz and Carnaveli (1970b)
Bulls	Maize meal[5]	40.0	—	—	Improved performance	Montilla (1971)
Zebu steers	Cottonseed meal, maize, molasses-urea, silage and grass[5]	Supplementary feeding	—	—	Higher live weight gain, reduced cost of feeding (9%)	Gontijo et al. (1972)
Friesian steers	Dried grass	21.0, 42.0	—	—	No difference	Ahmed and Kay (1975)
Kedah-Kelantan calves	Grass, copra cake, molasses urea[8]	30.0	—	—	Increased daily gain, feed efficiency, age at first service	Devendra and Lee Kok Choo (1975)
Native calves	Chopped grass, molasses-urea	20.0	—	—	Increased live weight gain	Labre et al. (1975)
Kedah-Kelantan calves	Grass, copra cake, molasses-urea	30.0, 40.0, 60.0, 80.0	—	—	Significant difference in daily live weight gain and feed efficiency	Devendra and Lee Kok Choo (1976a)
Kedah-Kelantan heifers	Grass, copra cake, molasses-urea	30.0, 40.0, 60.0, 80.0	—	—	Improved carcass characteristics	Devendra and Lee Kok Choo (1976b)
Steers	Grass	—	25.0, 50.0 leaves + stems	—	Increased live weight gain and feed efficiency	Moore (1976)

[1]Substituting potato flour in the diet.
[2]Substituting maize gluten in the diet.
[3]Substituting beet pulp in the diet.
[4]Substituting maize in the diet.
[5]Supplementary feeding.
[6]Substituting oats in the diet.
[7]Substituting barley.
[8]Substituting molasses.

Table 4. The effect of feeding cassava or molasses on the utilization of urea in West African woolless sheep (Chicco et al. 1971).[1]

	Hay[2]	Hay + cassava	Hay + molasses
Body weight gain			
(male)	88.3	100.9	106.7
(female)	59.9	86.5	83.2
Bacterial protein (mgN/100 ml)	159.3	193.0	175.5
Blood urea (mg/100 ml)	15.6	20.7	19.8
Acetic acid (mM/l)	68.7	59.9	61.9
Propionic acid (mM/l)	11.7	13.4	12.8
Butyric acid (mM/l)	8.3	12.2	13.3
Digestibility of organic matter (%)	59.6	66.6	70.7

[1]Significant differences ($p < 0.01$) were observed for all treatments and all parameters.
[2]Basal diet (% by weight) 50 ground pangola grass, 22 corn bran, 20 ground corn cobs, 5 molasses, 2 urea, and 1 mineral mixture. Supplementation of this hay diet was made by substitution of the corn cobs with molasses or cassava.

with varying levels of dietary nitrogen (20–80% levels of cassava in molasses-urea-fish meal diets with 6–12% levels of crude protein, 4 treatments); and trial 5, the effect of DL-methionine supplementation in isonitrogenous diets (40–80% levels of cassava with 0.2–0.6% methionine in molasses-urea diets, isonitrogenous, 9 treatments).

Cassava chips, mainly from a sweet variety, were used in all studies. The roots were washed, chipped to approximately 4–6 cm lengths, and sun dried. The average chemical composition of the chips (percentage dry matter) was: 1.7 crude protein, 3.2 crude fibre, 0.8 ether extract, 2.2 ash, 92.1 NFE, 0.091 calcium, 0.121 phosphorus, and gross energy 15.6 MJ/kg. This chemical composition is similar to that reported by others (Oyenuga 1955; Maner 1972; Müller et al. 1974b). The approximate HCN content was 90–100 mg/kg fresh material.

Trial 1

The digestibility of dry matter in the rice straw-based diets increased significantly ($p < 0.05$) with the inclusion of dietary cassava. No differences were noted, however, within the treatments with or without cassava inclusion (Table 5). This trend was also noted for significant ($p < 0.05$) differences in crude protein, crude fibre, and ash digestibility. The addition of cassava significantly ($p < 0.05$) increased nitrogen (N) retention, and all treatments with cassava recorded higher retention, the highest retention being 48.9%.

Trial 2

The digestibility of dry matter significantly decreased with increasing level of cassava inclusion ($p < 0.05$). The highest digestibility of dry matter (74.4%) was noted for the 20% level of cassava inclusion (Table 6).

The highest digestibility of crude protein was also recorded for the 20% level of cassava inclusion. However, the differences were not significant, and this trend was also evident for crude fibre, ash, ether extract, nitrogen-free

Table 5. Apparent digestibility of the main proximate constituents (%), trial 1 (each value is the mean of 3 sheep).

	Treatments[1]										L.S.D.
	1	2	3	4	5	6	7	8	9	10	($p=0.05$)
Dry matter	63.8	61.4	63.9	64.0	59.6	62.3	66.4	64.8	65.7	63.7	5.01
Organic matter	68.2	65.9	68.7	68.6	64.5	66.8	71.3	67.1	70.4	67.6	n.s.
Crude protein	48.0	52.9	63.7	69.3	57.4	47.0	61.8	66.4	72.3	72.3	8.35
Crude fibre	38.0	28.5	25.3	23.1	25.8	62.5	67.3	70.5	56.2	67.6	19.18
Ash	37.4	29.7	32.7	35.5	25.2	39.4	40.8	54.2	41.2	41.2	13.92
Ether extract											
Nitrogen-free extract	76.4	74.9	77.1	76.1	74.5	72.6	75.9	64.9	67.9	65.7	n.s.
Energy	73.5	71.2	74.5	73.2	74.2	76.2	75.7	76.4	77.2	71.4	n.s.
N retention as % of intake	8.1	29.6	36.7	18.1	−1.1	30.3	41.3	48.9	42.5	36.6	19.81

[1]Diets 1–5 (without cassava) consisted of: 30% rice straw, 65.9–68.9% molasses, 1.1–4.1% urea, and 1% mineral mixture; diets 6–10 (with cassava) consisted of: 30% rice straw, 45.9–48.9% molasses, 1.1–4.1% urea, and 1.0% mineral mixture.

Table 6. Apparent digestibility of the main proximate constituents (%), trial 2 (each value is the mean of 3 sheep).

	Treatments[1]					L.S.D. ($p = 0.05$)
	1	2	3	4	5	
Dry matter	66.9	74.4	71.5	67.1	61.9	7.68
Organic matter	75.7	79.8	76.8	75.1	70.5	n.s.
Crude protein	53.4	62.4	54.2	47.5	53.0	n.s.
Crude fibre	31.2	33.4	29.7	29.9	30.9	n.s.
Ash	22.4	13.2	19.8	22.5	17.5	n.s.
Ether extract	81.7	79.4	74.5	75.6	73.6	n.s.
Nitrogen-free extract	84.2	92.4	89.4	83.7	75.7	n.s.
Energy	73.6	76.4	70.7	65.9	65.2	n.s.
N retention as % of intake	52.9	62.1	53.9	47.4	52.5	n.s.

[1]Diets consisted of: 20% rice straw, 0–75.4% molasses, 0–75.0% cassava, 3.6% urea, and 1.0% mineral mixture.

Table 7. Apparent digestibility of the main proximate constituents (%), trial 3 (each value is the mean of 4 sheep)

	Treatments[1]				L.D.S. ($p = 0.05$)
	1	2	3	4	
Dry matter	93.2	86.9	88.9	79.9	5.67
Organic matter	94.8	87.5	89.2	83.5	6.21
Crude protein	92.6	74.5	73.2	75.0	9.74
Crude fibre	27.9	28.9	42.7	29.4	n.s.
Ash	81.5	77.0	70.7	38.1	17.92
Ether extract	84.2	79.4	78.7	74.7	n.s.
Nitrogen-free extract	95.0	43.7	48.8	62.4	16.88
Energy	90.5	65.7	81.8	78.7	17.21
N retention as % of intake	73.7	64.5	63.1	69.0	6.25

[1]Diets consisted of: 20–80% cassava, 15.3–75.2% molasses, 3.7–3.8% urea, and 1% mineral mixture.

extract, and energy digestibility. The nitrogen retention as a percentage of intake was also highest for the 20% level of inclusion. No differences were found between the rice straw + molasses (treatment 1) and rice straw + cassava (treatment 5) in nitrogen retention.

Trial 3

The effect of increasing cassava from 20 to 80% in the diet was reflected in a statistically significant ($p < 0.05$) decrease in the digestibility of dry matter. With 80% cassava in the diet, the digestibility of dry matter decreased to 79.9% compared with 93.2% for the 20% level of inclusion (Table 7). A similar trend was also noted for organic matter, crude protein, ash, ether extract, nitrogen-free extract, and energy digestibilities.

Crude protein digestibility was not significantly different between the 40, 60, and 80% levels of cassava inclusion, but these treatments were significantly ($p < 0.05$) different to the 20% level of inclusion. A parallel finding was also noted for N retention.

Trial 4

The digestibility of dry matter decreased significantly ($p < 0.05$) with increasing levels of cassava inclusion. The highest digestibility of dry matter was noted for the 20% level of inclusion (94.5%). A parallel trend was noted for organic matter digestibility (Table 8).

The digestibility of crude protein was highest (71.2%) for the 20% level of cassava inclusion with 47.7% of molasses. N retention was significantly different between treatments ($p < 0.05$). Ash digestibility decreased significantly ($p < 0.05$) with increasing levels of cassava inclusion.

Trial 5

Concerning methionine supplementation

Table 8. Apparent digestibility of the main proximate constituents (%), trial 4 (each value is the mean of 3 sheep).

	Treatments[1]				L.S.D. ($p = 0.05$)
	1	2	3	4	
Dry matter	94.5	85.7	84.2	83.1	n.s.
Organic matter	95.1	89.3	87.9	87.1	n.s.
Crude protein	71.2	65.4	62.1	68.2	n.s.
Crude fibre	21.9	22.7	23.9	22.7	n.s.
Ash	78.9	56.0	48.8	27.9	11.09
Ether extract					
Nitrogen-free extract	85.2	80.2	80.3	81.2	n.s.
Energy	94.6	87.9	87.9	84.2	n.s.
N retention as % of intake	84.7	68.0	77.5	74.2	11.21

[1]Diets consisted of: 20–80% cassava, 3.6–47.7% molasses, 3.1–7.0% fish meal, 1.0–2.4% urea, and 1.0% mineral mixture.

Table 9. Apparent digestibility of the main proximate constituents (%), trial 5 (each value is the mean of 3 sheep).

	Treatments[1]									L.S.D. ($p = 0.05$)
	1	2	3	4	5	6	7	8	9	
Dry matter	88.3	85.5	82.2	84.2	85.0	85.5	84.2	86.4	87.3	n.s.
Organic matter	90.8	88.2	85.7	87.9	87.9	88.8	88.1	89.4	89.7	n.s.
Crude protein	78.8	73.7	72.3	72.9	73.2	76.2	80.7	77.8	79.9	n.s.
Crude fibre	21.5	22.9	29.3	19.9	23.5	26.8	39.4	43.7	47.7	18.41
Ash	53.8	44.3	38.5	30.0	44.6	43.6	51.6	41.7	44.5	n.s.
Ether extract	99.0	98.7	98.6	98.4	97.3	98.7	98.8	98.9	98.5	n.s.
Nitrogen-free extract	94.3	92.5	90.9	93.3	93.2	92.8	91.8	93.8	93.5	n.s.
Energy	89.2	87.0	90.0	82.8	86.5	86.4	84.3	94.2	96.8	n.s.
N retention as % of intake	78.5	73.5	72.0	72.7	73.0	76.0	80.6	77.5	79.8	n.s.

[1]Level of cassava inclusion in molasses-urea diets in treatments 1–3 was 40%, 4–6 was 60%, and 7–9 was 80%.

with increasing levels of dietary cassava, no significant differences were noted in the digestibility of dry and organic matter, crude protein, ash, ether extract, nitrogen-free extract, and energy digestibility (Table 9). N retention was also not significant between treatments, but tended to increase with 80% cassava in the diet.

However, statistically significant differences were noted for crude fibre digestibility ($p < 0.05$), especially between the 80% level of cassava inclusion and 40 and 60% levels. The highest crude fibre digestibility (47.7%) was noted for an 80% level of cassava inclusion supplemented with 0.6% methionine. Within each level of cassava inclusion, there was a tendency for crude fibre digestibility to increase with increasing levels of methionine supplementation, but these differences were not significant.

Pattern of Starch Digestion

In trials 2, 3, and 4, the digestibility of increasing levels of cassava in the diet indicated that the highest digestibility was consistently noted for the 20% level of inclusion (Tables 6–8). The values for digestibility of dry matter in these trials were 74.4, 93.2, and 94.5%. The relatively low value of 74.4% in trial 2 was due to the presence of rice straw in the diet, which was not included in trials 3 and 4. These digestibility values are very high, and although a 20% level of cassava is implicated, it is important to stress that higher levels are also well digested. In trials 3 and 4 for example, an 80% level of cassava inclusion gave a relatively lower, but nevertheless high dry matter digestibility of 79.9 and 83.1%. Confirmation that a lower level of cassava in the diet is more advantageous is also reflected by the results of Roverso et al. (1969) and Deven-

dra and Lee Kok Choo (1976a). However, although higher levels may be beneficial for beef cattle fattening because of the supply of increased glucose precursors, this may be antagonistic for dairy cattle feeding.

Associated with the high values for the apparent digestibility of dry matter for the 20% level of cassava inclusion, was an equally high crude protein digestibility and also N retention. This was noted in the results of trials 2, 3, and 4.

Only limited evidence exists about the nature of rumen fermentation consequent to cassava feeding. It appears that cassava feeding gave more propionic acid than molasses (Table 4), and since a greater molar percentage of butyric acid is produced in the latter, cassava feeding is therefore energetically more advantageous. In the rumen, the breakdown of starch is dependent on the proportion of amylolytic to nonamylolytic bacteria. The tendency toward reduced digestibility with increasing levels of cassava inclusion suggests, however, that considerable quantities of starch escaped from the rumen without fermentation. This is distinctly possible, since dietary roughage was low and was chopped when fed. If high levels of cassava are to be efficiently utilized, therefore, digestion in the intestinal tract posterior to the rumen assumes considerable significance, as has been forcibly demonstrated by the studies of Karr et al. (1966). They showed in steers fed 5-kg daily rations containing 20, 40, 60, or 80% ground maize, that the percentage of starch digested in the rumen fell progressively from 84–72% to 64–62% as the dietary maize level was increased. They rightly suggested that amylolytic activity in the small intestine was implicated.

In steers, Clary et al. (1966) showed that amylase activity, expressed as amount of starch digested per unit of enzyme protein, was 588 ± 61 and 827 ± 61 for unsupplemented pasture and all concentrate diets, respectively. In further studies, Clary et al. 1967a showed that the relative amylase activity increased as the amount of starch in the diet rose with commensurate changes in glucose concentration of jugular blood. It is possible, however, that the intestinal enzymes digest starch less efficiently when larger, rather than smaller, quantities require digestion.

Amylolytic activity cannot account entirely for the efficiency of starch digestion because the nature of the dietary starch is also important. Clary et al. (1967b) reported that although ruminants were more effective than swine in breaking down starch fragments, they were less efficient in attacking intact starch molecules. Tucker et al. (1966) reported similar findings in sheep. Because it is possible that the nature of the cassava fed could be involved in the reduced digestibility, it is essential to indicate precisely the type of cassava that is fed. There is no doubt that the total amount of starch utilized by the intestinal route increases with the amount of starch consumed daily (Little et al., 1968), including utilization in the large intestine. Additionally, low levels of starch utilization can result from feeding a liquid diet (Huber et al. 1967a); therefore, method of feeding is also involved.

Associated with these observations is the point that very little is known about the effect of processing (for example, type of chips and pellets) cassava on its feeding value and utilization by ruminants. Because processing tends to improve feed efficiency, it is essential to identify the type of cassava fed. Cooking cassava and urea prior to feeding to cattle reduces rumen ammonia and blood urea, suggesting that this is more advantageous than the uncooked diet (Shultz et al. 1970a).

Utilization of Nitrogen

In view of the importance of nitrogen (N) utilization in the ruminant, especially under the influence of various types of carbohydrate sources, it is of interest to consider this aspect in some detail. This examination was also stimulated by the use in our studies of both preformed and nonprotein nitrogen (NPN) sources like urea. In particular, it was of interest to ascertain the value of added cassava in the rice straw-molasses diets, especially for retained N in the balanced studies (Table 10).

In rice straw-molasses diets with or without added cassava, where the dietary crude protein content varied from 5.8 to 14.2%, it was found the N retention increased until treatment 3 with a crude protein content of about 10% and then declined significantly ($p < 0.01$). With cassava, the N retention was higher for every treatment, and was again highest for the 10% level of dietary crude protein. Significant differences ($p < 0.05$) were noted in the N content of feces and urine between treatments with or without cassava addition. N intake and N retention were not correlated without

Table 10. Nitrogen (N) balance data for trial 1 (each value is the mean for 3 sheep).

Constituent	Treatments[1]										L.S.D. ($p = 0.05$)
	1	2	3	4	5	6	7	8	9	10	
N intake (g)	7.05	0.87	10.33	12.62	11.28	8.92	13.66	13.91	17.90	20.24	4.68
N in feces (g)	3.59	3.78	3.75	3.86	4.75	4.71	5.26	4.74	4.88	5.64	1.72
N in urine (g)	2.54	1.97	2.59	6.30	6.63	1.50	2.64	2.50	5.34	7.59	1.93
N retention (g)	0.92	2.31	3.80	2.47	−0.10	2.72	5.76	6.67	7.58	7.50	3.02
N retention as % of intake	8.8	29.6	36.7	18.1	−1.1	30.3	41.3	48.9	42.4	36.6	16.81
N absorbed (g)	3.12	4.27	6.58	8.77	6.53	4.22	8.41	9.17	13.02	14.60	3.45
N retention as % of N absorbed	16.5	56.3	56.8	25.8	−2.3	64.6	67.2	73.2	58.6	50.8	31.54
N in feces as % of N intake	52.0	47.1	36.3	30.7	42.6	53.0	38.3	33.6	27.7	27.7	8.36
N in urine as % of N intake	38.2	23.2	26.9	51.2	58.6	16.7	20.4	17.5	30.0	36.6	16.38

[1]Diets 1–5 (without cassava) consisted of: 30% rice straw, 65.9–68.9% molasses, 1.1–4.1% urea, and 1.0% mineral mixture; diets 6–10 (with cassava) consisted of: 30% rice straw, 45.9–48.9% molasses, 1.1–4.1% urea, and 1% mineral mixture.

cassava, but with the addition of cassava, N intake was significantly correlated to N retention ($r = 0.898$, $p < 0.01$).

The N balance data from trial 1 (Table 10) and N retention data from trial 2 demonstrate the value of cassava for enhancing N utilization and therefore N retention. In trials 1, 2, and 3, all the N was contributed by urea in the diet; whereas, in trial 4, urea only contributed approximately 62–63% of the total crude protein requirement. This trial also gave the highest N retention of 74.2% compared with 18.1–42.5% in trial 1, 47.4–62.1% in trial 2 (Table 6), and 69.0% in trial 3 (Table 7) for similar levels of dietary crude protein (12.0%). This supports several reports that have demonstrated that approximately 60–70% of the total N requirements can be obtained from urea (Hume 1970; Hume and Bird 1970; Ramirez and Kowalczik 1970; Sutton et al. 1970; Walker 1970; Devendra 1976b).

The utilization and retention of dietary N are influenced to a large extent by the type of carbohydrate present, and the N balance data in Table 10 also emphasize this point. The amount of microbial proteins synthesized is dictated by the amount of readily available carbohydrates, especially those that can be readily fermented in the rumen (Pearson and Smith 1943; Annison et al. 1954; Belasco 1956; Lewis and McDonald 1958; Elliott et al. 1961; Karue 1973). In the presence of these readily available carbohydrates and therefore energy, the amount of proteins leaving the pylorus is greater than the amount supplied in the diet (Gray et al. 1958; Clarke et al. 1966; McIntyre and Williams 1970) because of microbial synthesis of protein in the rumen from endogenous N sources, particularly urea. A higher rate of synthesis of microbial proteins, reflective of a low rumen ammonia concentration and high bacterial N, has been reported for cassava supplemented diets compared with maize (Chicco et al. 1970; Shultz et al. 1970a; Soewardi et al. 1975).

In four of the five trials reported, urea represented the main source of protein in the diet, and its effective utilization was largely dependent on the concurrent use of cassava. Although cassava enhanced urea utilization and retention in trial 1, the results of substituting molasses with cassava in trial 2 suggest that in terms of N retention in isonitrogenous diets, there were no significant differences between the two. However, support for the value of cassava in enhancing urea is evident from sev-

eral studies that have reported utilization in comparison with other carbohydrate sources such as maize or molasses (Shultz et al. 1970a; Chicco et al. 1971; Joshi and Majumdar 1972; Soewardi et al. 1975). In rice straw-molasses based diets, such as those used in trials 1 and 2, the value of adding to or replacing part of the molasses in the diet is associated with the fact that the net energy value of molasses is considerably reduced beyond 30% dry matter in steers and dairy cows (Lofgreen 1965; Lofgreen and Otagaki 1960).

In the N balance data in trial 1 (Table 10), the percentage of ingested N lost in the urine increased with increasing dietary urea, and supports similar observations by Huber et al. (1967a,b) and Devendra (1976a). On the other hand, this differs from the reports on utilization of urea by Zebu cattle and buffalo by Razdan et al. (1971).

Although methionine supplementation produced no significant differences in the digestibility of the main proximate components, it is interesting to note that crude fibre digestibility was significantly different ($p < 0.05$), and increased with increasing level of cassava inclusion. This suggests that methionine may be important in the activity of cellulolytic rumen bacteria, and the observation is consistent with the report of Johnson et al. (1949) that sulfur containing amino acids (cystine and methionine) are important components of rumen bacteria.

Additionally, the N retention data in Table 6, although not significantly different, gave consistently higher (72.0–80.6%) values compared to the treatments with the same levels of crude protein content in trials 2 and 3, in treatments 4 and 10 in trial 1, and in treatment 4 of trial 4. Methionine supplementation is obviously implicated, and enhancement of the value of dietary urea with its supplementation finds support in the results of Harris and Mitchell (1941), Loosli and Harris (1945), and Lofgreen et al. (1947).

HCN Toxicity in Ruminants

Very little is known about HCN toxicity in ruminants, and present evidence suggests that feeding high levels (20–80%) of cassava chips (Tables 6–9) and chopped roots does not produce any ill effects. This may perhaps be due to the fact that sweet varieties were fed, because feeding raw fresh leaves of bitter varieties as a forage (with 180–240 mg/kg fresh weight) has produced chronic toxicity and death. In a feeding trial involving Kambing Katjang weaner kids in Serdang, up to 40% mortality was noted within 2 weeks of starting the trial, and a deleterious effect was produced on live weight gain.

Nevertheless, white clover containing cyanogenic glycosides equivalent to 129 mg of cyanide per 100 g dry matter produced no deleterious effects in dairy cows, but plasma thiocynate increased, producing evidence for a metabolic effect (Butler et al. 1957). Several species of *Cynodon* with HCN in them have not been reported to have any serious effects in ruminants (see for example Henderson Research Station 1970). On the other hand, high levels of cyanogens (180 ppm HCN) and low levels of iodine (±0.05 ppm I) have been reported to cause thyroid dysfunction (Herrington et al. 1971) in sheep grazing *Cynodon plectostachys*. Worker (1957) noted that blood thiocynate levels were constant throughout the season in Jersey cows grazing white clover pastures, and that urinary clearance of thiocynate could be greater than in sheep; an alternative detoxicating mechanism has been suggested. There is need therefore to investigate the effect of cyanogen levels on toxicity and other deleterious effects on ruminants.

Future Lines of Research

This review suggests the need for much more research. Some areas in which research is required are: (1) the feeding value of sweet and bitter cassava varieties; (2) the relative nutritive value of leaves, stems, tubers, peelings, and pomace. The importance of the leaves as a protein source, tubers for energy supply, and leaves and stems as forage needs more investigation; (3) digestion and utilization of cassava in the rumen and in the intestinal tract posterior to the rumen; (4) associated with (3), the pattern of rumen fermentation, the nature of the microflora, amylolytic activity, and the effect of carbohydrate structure need appraisal; (5) the influence on the utilization of other dietary nutrients, including proteins; (6) carbohydrate structure, including the effect of processing; (7) the effect of nutritional management, for example, method of feeding and type of feed used; (8) problems associated with cyanogenic glucosides, toxicity, and possible thyroid dysfunction consequent to feeding cassava (species differences may be involved); and (9) development of appropriate feeding systems and technologies suited to cassava utilization by the ruminant.

Improving the Quality of Cassava Root and Leaf Product Technology

Z. Müller[1]

The importance of cassava in tropical nutrition is reviewed; the lower amylose content of cassava starch making this feed a suitable source of energy for ruminants. Aspects of quality are discussed with special emphasis on the content of critical nutrients in cassava root products.

Cassava chips are generally of higher quality than pellets, and both the shape and size of the chips were found to have very practical implications regarding the time required for sun drying. Thin slices (2 mm) spread over black painted floors can be dried on sunny days within 8 h or less; whereas, roughly chipped cassava takes several days to dry with detrimental results on quality and economic considerations.

Pelleting reduces the volume of cassava root products by 25–40%, which is an important freight-cost consideration. Aspects of both good and bad practices of pelleting cassava-based diets are discussed. One of the great advantages of cassava in ruminant nutrition is the slow release of N from the cassava-NPN complex.

The aerial part of the cassava plant can also be processed into leaf meal or pellets and is a good source of protein. Industrial production of leaf protein concentrate from cassava leaves by the PRO-XAN process offers new investment opportunities, despite its high capital intensive characteristics.

The tropical biosphere favours photosynthetic outputs in the form of structural (cellulose, lignin, etc.), rather than soluble (starches and sugars) carbohydrates. This appears to be the result of a plant evolutionary process that supports the structure of the plant and its resistance to chemical attack accentuated by the tropical climate. Structural carbohydrates, cellulose in particular, have been tantalizing scientists for centuries because their polymerized structure can be theoretically split into 3500 molecules of glucose. But the economic feasibility of liberating cellulose, locked in structural carbohydrates, still presents a challenge to scientific research.

The importance of cassava in tropical livestock nutrition arises from the fact that the deficiency of dietary energy in the form of soluble carbohydrates is more acute in the tropics because the forages are more fibrous, coarse, bulky, and less palatable than their temperate counterparts. Butterworth (1967) showed that at maturity 96% of all temperate grasses (from 760 samples) exhibited a TDN value over 55%; whereas, only 48% of the tropical grasses (from 312 samples) exhibited a TDN value over 55%. These realities are even more striking at individual vegetative stages. Whereas temperate grasses mature slowly, tropical grasses mature rapidly and their TDN value often drops below 35%.

[1]Asia Research Pte. Limited, P.O. Box 91, Alexandra P.O., Singapore 3.

Animal nutritionists in the tropics face the exceedingly difficult task of formulating livestock diets with adequate levels of available energy. This phenomenon is directly relevant to cassava root products for self-sufficient livestock production in the tropics. Tropical forages, and most tropical feedstuffs (with the exception of starchy root products, sago, and molasses) are highly contaminated by cell-wall, lignin, cutin, and silica (Table 1).

Tropical feedstuffs with high levels of structural carbohydrates, such as rice bran or copra meal, when fed together with tropical forages induce physiological control of the feed intake by ruminants. A similar situation exists in diets for pigs and poultry when rice bran, copra cake, palm kernel products, and other tropical feedstuffs, with similar nutritive profiles, represent a substantial portion of the feeding ration.

Moreover, animals indigenous to the tropics usually have a smaller frame and a relatively smaller cavity in their gastro-intestinal track; thus the accumulation of indigestibles derived from poor forage further limits feed intake. On this premise, animals in the tropics tend to disregard our textbook knowledge concerning caloric concentration in weight units (cal/kg), recognizing the caloric values in terms of density (cal/litre). This is particularly true of mature animals (lactating cows, finishing cattle, lactating sows, and laying hens). It is therefore rather misleading to en-

Table 1. Percentage of structural carbohydrates on a dry matter basis in some tropical feedstuffs and forages (Müller 1976).

	Crude fibre	Crude lignin	Cutin	Silica
Cassava root meal	4	0.2	—	—
Sago meal	4	0.3	—	—
Rice bran	14	4.5	1.2	4.1
Palm kernel meal	12	4.2	0.6	—
Cotton seed meal	14	5.1	2.3	—
Copra meal	13	4.7	0.7	—
Napier grass (6 wks)	28	6.2	0.7	1.1
Pangola grass (6 wks)	25	5.3	0.5	0.9
Stylosanthes (bloom)	22	6.4	1.7	0.8

thuse over the striking feed energy yields of tropical crops, quoted in statistics, because statistics tend to classify the photosynthetic output in terms of gross energy, giving fibres, starches, and sugars equal value. The caloric content (Mcal/kg) of some carbohydrates is: glucose 3.74; fructose 3.76; sucrose 3.97; maltose 3.95; lactose 3.95; dextrine 4.12; cellulose 4.19; and starch 4.21 (Kolb 1966).

In practical terms, however, the actual nutritive values of soluble and structural carbohydrates differ greatly, considering the physical and physiological limitations imposed by environmental factors that interfere with feed intake. This is the main reason why the supplementation of tropical forages by cassava and other donors of soluble carbohydrates have such a dramatic impact on livestock performance compared with other tropical "concentrates" such as rice bran, copra cake, or palm kernel meal.

Cassava Root Products

One of the specific features of cassava root products is their lower amylose content compared with other starchy carriers, for example, on a dry matter basis cassava has 17, sago 27, potato 22, and maize 21% amylose (Kolb 1966). Amylose is the inner soluble portion; whereas, amylopectin is the outer portion of the starch molecule. Although both are hexosans (polymers of glucose) their depolymerization process during digestion is different. The apparently higher amylopectin content of cassava starch predetermines this starchy feed as a suitable source of energy for ruminants, particularly when fed in conjunction with higher levels of NPN compounds.

To produce 1 tonne of dry cassava (14% moisture) requires about 2.7 tonnes of fresh roots. The shorter the drying period the higher the caloric value of the final product. But, regrettably, the cassava trade goes through many hands: farmer, subdealer, dealer, miller, exporter, and importer. Because cassava is usually produced by smallholders the quality of the product differs considerably with farming and processing methods and with varying soil conditions, not to mention the probity of the farmer. Unfortunately, in many countries the adulteration of cassava is the main quality problem because standards are usually too loose (Table 2). A contributing factor to low quality cassava is the narrow difference in price levels between low and good quality cassava, which does not offer a sufficient incentive to the farmer to produce a better product.

Table 3 compares the chemical composition of exported cassava root products (and thus their quality) from some Asian countries. As Khajarern et al. (1977) have pointed out, pellets are more often adulterated than chips. An analytical survey of samples collected from the Khon Kaen Region (Thailand) gave the following values (%) for moisture (M), crude fibre (CF), and ash (A): commercial chips 12.4 M, 2.82 CF, 3.32 A; commercial pellets 13.1 M, 2.50 CF, 4.16 A; and commercial chips (washed and partly pealed) 9.4 M, 2.18 CF, and 2.21 A.

Production of Cassava Chips

The production of cassava chips is a simple mechanical process involving either a slicer, cutter, or shredder. The highest efficiency has been achieved with slicers similar to those used in the sugar beet industry. Washing and peeling of the root results in a better product, with a lower content of ash, fibre, and cyanogenic compounds.

Table 2. Comparison of optimal and minimal nutritive values (%) of unadulterated cassava root products with Thai standard.

	Thai standard (minimum requirement)[1]	Nutritive value of cassava	
		Minimal value	Optimal value
Moisture	14.0 (<14.3)	14.0	14.0
Soluble carbohydrate	70.0 (>68.0)	75.0	78.0
Crude fibre	5.0 (<7.0)	3.5	2.5
Ash	3.0 (<5.0)	3.0	2.5

[1]Shipments can be refused that do not meet these requirements.

Table 3. Content of critical nutrients in cassava root products entering Singapore from various Asian countries, averages given in parentheses (Muller 1974).

	Moisture (%)	Crude fibre (%)	Ash (%)
Thailand (14 samples)	9.8–13.9 (12.2)	3.3–7.9 (4.7)	2.6–6.9 (4.9)
Indonesia (23 samples)	11.3–14.2 (12.8)	2.6–4.0 (3.2)	1.7–3.8 (3.5)
Malaysia (8 samples)	10.8–14.4 (12.9)	2.6–3.8 (3.0)	1.6–4.3 (3.4)
Mainland China (22 samples)	10.3–12.4 (11.0)	1.9–3.2 (2.5)	1.5–2.9 (2.2)

Table 4. The effect of the shape and size of sun-dried cassava chips dried on either black or white cement on the moisture content (%) of the final product (Thanh 1976).

	Moisture content (%) after 20 h			
	White cement floor		Black cement floor	
Chip shape and size (mm)	29 °C/30 °C[1]	28 °C/29 °C	31 °C/32.5 °C	31.5 °C/32 °C
Circular chips (t × d)[2]				
5 × 45	27.6	13.1	16.6	8.6 (12 h)[3]
10 × 45	47.5	30.2	36.8	30.4
Rectangular blocks (l × w × t)				
80 × 25 × 5	32.2	15.1	17.2	12.4 (12 h)
80 × 50 × 5	36.7	17.0	16.9	11.3 (12 h)
80 × 25 × 10	37.2	23.3	35.9	28.3
80 × 50 × 10	47.7	34.6	39.2	31.4
Cubes (l × w × t)				
10 × 10 × 10	21.3	14.6 (16 h)	15.3	9.7 (8 h)
20 × 20 × 20	39.8	33.2	37.1	25.8
Strips (l × w × t)				
80 × 5 × 5	17.5	16.2	13.2 (18 h)	7.4 (8 h)
Slices (t)				
2	13.8	13.1 (16 h)	10.6 (18 h)	6.9 (8 h)

[1]The first temperature is the ambient temperature, the second is the floor temperature.
[2]d = diameter, t = thickness, l = length, and w = width.
[3]The number of hours in parentheses refers to the time required to reduce the moisture content to 15%, the recorded value is the moisture content after 20 h.

Chips (10–15 kg/m²) are spread on concrete floors and sun-dried in 1 or 2 days. Apart from climatic factors, the speed of drying depends upon their shape, and the size and colour of the concrete drying area. Several tests carried out by the Asian Institute of Technology in Bangkok, Thailand (Thanh et al. 1976) showed that by using the proper technology, drying time can be dramatically reduced (Table 4). These experiments have

practical application on the quality of cassava root products: the quicker the drying process the less loss of feed energy through fermentation and the lower the level of microbial contamination.

Cassava Pellets

The commercial purpose of pelleting cassava root products is to decrease the volume by 25–40% (freight-cost criterion); to produce a uniform product; to facilitate handling during transport, loading, unloading; and to eliminate the dustiness of the product. The history of cassava pellets is not too good because the old pelleting machines were not designed for starchy materials and thus the output and quality were low. This was further affected by the addition of mineral and fibrous adulterants, which significantly shortened the die life of the machines, and made the pellets so fragile that they hardly survived the first handling. Thus, the benefits of pelleting were usually lost.

The introduction of modern pelleting plants has contributed significantly to the density, durability, and quality of pellets, on one hand, and to economics on the other. The addition of moisture and/or heat increases the effectiveness of the pelleting machines in terms of output, die life, energy savings, volume reduction, and nutritive value, and results in better utilization of cassava roots by animals. Although the mode of action of the improved utilization has not been established, it is suggested that the chemical alteration of the starch and other constituents improves the digestibility of nutrients, including the crude fibre and protein of the endosperm (Müller et al. 1975).

Pelleting of Cassava-Based Diets

To achieve high quality when pelleting cassava-based diets it should be recognized that different steam pressures and differing volumes of steam are required for different levels of cassava in the diet. The temperature, particularly in the absence of moisture, must be carefully controlled in diets containing sugars (sucrose, molasses, whey, milk, etc.) on the one hand, and donors of NH_2 groups (urea) on the other, because high temperatures in the presence of sugars may support the formation of Maillard products. The Maillard reaction is irreversible and protein bound in this process is lost (Mertens 1977).

The proper levels of supplied heat and heat generated during the pelleting process improve protein digestibility and in some feeds destroy antitryptic substances (urease). Because cassava diets for monogastric species must be pelleted to ensure their proper intake, the heat level should not exceed 70 °C to avoid protein degradation. Excessive heat can support a nonenzymatic browning or Maillard reaction in which sugar-aldehyde groups react with amino acids.

Although one should be suspicious of any browning process it is not always attributable to a Maillard reaction. The high temperatures used during the pelleting of cassava roots may result in the transformation of a portion of the starch into dextrines, which result in a light yellow or brown colour appearing on the surface of the pellet. This process is not detrimental to the nutritional quality of the product.

Overheating cassava-based diets during the pelleting process causes significant damage to the utilization of protein by monogastric animals; however, it is usually beneficial to ruminants. If this process can be controlled in terms of decreased solubility of protein, and thus their slower degradation in the rumen, without affecting postabomasal protein digestibility, it improves N retention, performance, and feed efficiency (Chalupa 1975).

Cassava-NPN Complex with Slow Nitrogen Release

Urea being a 100% soluble source of nitrogen does not ensure optimum conditions for microbial proteosynthesis in the rumen. These negative effects of urea on fermentative processes in the rumen can be moderated by starch carriers that reduce the solubility of the urea and time its release for ruminal synthesis. In this respect cassava has a good commercial potential. There are basically two processes designed for slow nitrogen release from urea: mechanical treatment and chemical treatment.

The process of NPN incorporation by mechanical means involves the incorporation of NPN (urea) and other ingredients into cassava starch which, during the process, undergoes geletanization — a radical change in the molecular arrangement. Cassava, urea, and other ingredients (bentonide, H_3PO_4, Na_2SO_4, NaCl, microelements, and vitamins) are treated in the extruder. The final product is an elastic, semisolid mass that serves, after drying and grinding, as a rich source of slow

Table 5. Chemical analyses (% dry matter) of leaves collected in Thailand during the wet and dry seasons and in different development stages (in weeks) (Holm 1971 cited by Göhl 1975).

	Wet season			Dry season		
	4 weeks (70 cm)	6 weeks (100 cm)	8 weeks (135 cm)	4 weeks (50 cm)	6 weeks (60 cm)	8 weeks (65 cm)
Dry matter	15.3	14.5	16.1	17.8	16.2	18.5
Crude protein	24.8	22.8	24.1	25.8	29.0	25.4
Ether extract	5.2	6.2	5.0	5.6	6.2	7.0
Crude fibre	18.3	22.8	26.0	15.2	16.7	18.4
NFE	43.2	40.6	39.9	45.0	39.5	40.6
Ash	8.5	7.6	8.0	8.4	8.6	8.6
Ca	0.98	1.03	0.99	1.18	1.17	1.41
P	0.52	0.55	0.56	0.73	0.62	0.59

release NPN for ruminants. The product, containing 55–70% crude protein (NPN derived), in comparison to urea is much better utilized by ruminants (60–70% digestibility) because its lower solubility promotes greater protein retention.

The chemical process for NPN incorporation is based on the urea-formaldehyde technology developed by Kadawaki in 1936. Urea and formaldehyde are mixed with the cassava root. A chemical reaction takes place during the pelleting or extruding process aided by steam. The temperature inside the pellets should be between 60 and 80 °C to support the methylization of the formaldehyde and thus the formation of methylene ureas rather than tetra-, penta-, and hexaurea, which would be formed at higher temperatures. The final product has a very low bacterial count and contains a variety of polymers with different nitrogen release times. The crude protein content would depend upon the cassava:urea ratio. A level of 12–15% urea would result in 35–43% crude protein (NPN-derived) in the final product, which is well utilized by ruminants.

The Aerial Parts of Cassava

Leaf Meal and Pellets

Cassava leaves are a good source of protein; the protein level being much higher than that of tropical legumes. The yield of leaves is similar to that of roots (about 10 t/ha) but by close planting and nitrogen fertilization it is possible to obtain a much higher level of vegetative growth (40 t/ha or more). The aerial part should not be harvested later than 4–5 months after planting otherwise the development of the root is seriously affected. Limited quantities of leaves can be harvested at any time during the vegetative stage but always at the expense of lower root yields.

Apart from their high protein content and relatively low level of crude fibre, the leaves are very rich in ether extract, which can be attributed to high levels of chlorophyll and xanthophylls (Table 5). The content of calcium and phosphorus is also relatively high.

Because of the architecture of the plant, sun drying of leaves is quite easy and they can be dried within a few hours on sunny days. Dry leaves are preserved either in the form of leaf meal or pellets. Pelleting in the absence of steam inevitably results in some Maillard products and mild damage to the protein, which exhibits lower solubility. This is beneficial to ruminants but not to monogastric animals; therefore, leaf meal is more suitable for pig and poultry diets; pellets are more suitable for ruminants.

Leaf Protein Concentrate

The aerial part of the cassava plant also offers potential for recovery of leaf protein, either for human consumption or for monogastric animals. Research, supported by IDRC, is currently being carried out in Colombia, Nigeria, and other countries. The commercial potential of the utilization of the aerial part of cassava by a modification of the PRO-XAN process is shown in Fig. 1.

Although the technology has been well established there are some limitations in the protein output as described by Kohler and Bickoff (1971): (1) only 70–75% of the nitrogen in the leaf is in the form of true protein, and although 60% of the nonprotein nitrogen is in the form of free amino acids, these are

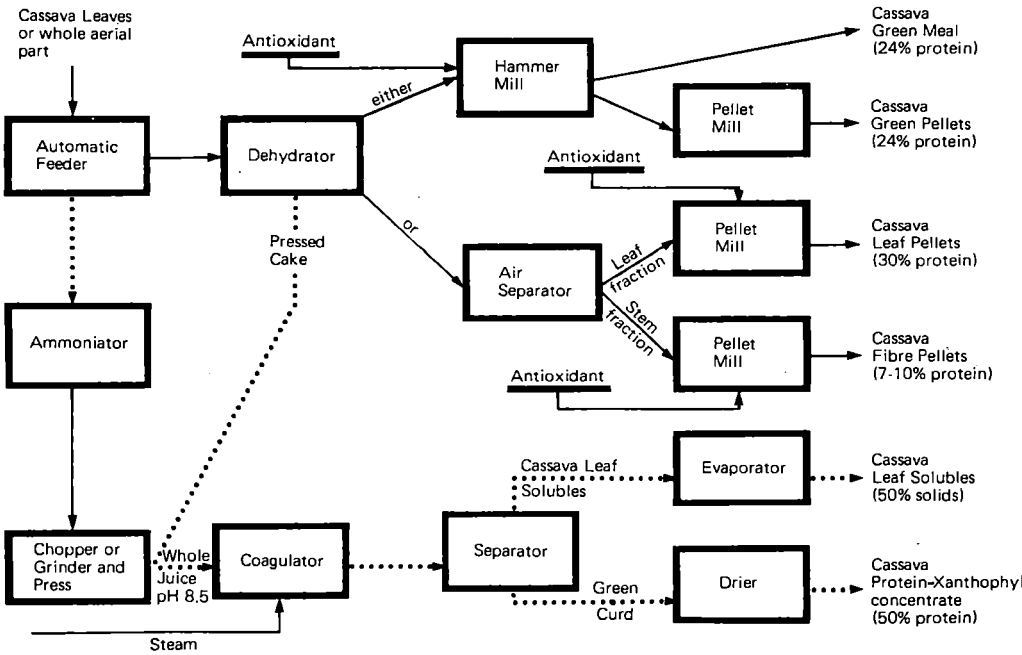


Fig. 1. The commercial potential of the utilization of the aerial part of the cassava plant (modification of the PRO-XAN process).

not recoverable in the usual coagulation step to obtain protein; (2) the ultimate protein yield depends on the number of cells broken in the maceration process, and hence on the amount of nitrogen made available for extraction from the plant material; and (3) during mechanical pressing of the nitrogen-rich juice from the fibre, a filtration system develops as a result of the fibrous mat that is formed on pressing the pulped material — protein, especially protein held in the chloroplasts, may then be held back limiting production yields.

The importance of defining the most suitable period of the vegetative stage (peak period) for the extraction of protein has recently been studied by Addy et al. with the following conclusions: (1) leaves should be harvested when foliar growth and nitrogen content reach the optimum protein yield; (2) the incidence and duration of the "peak period" is likely to be related to the growth rate — thus slower growing plants (dry season, low fertility of soil, variety, etc.) have delayed peak periods of longer duration; (3) the period of abundant foliage and maximum nitrogen availability is also accompanied by several physical and structural factors pertinent to the rupture of leaf cells, and hence to protein processing; (4) during the peak period, the leaf cells are more loosely packed, making possible larger deformations, and hence rupture (this conclusion must be qualified, however, by noting that the presence of greater airspace could increase the effect of cushioning the applied load, thereby reducing the force imparted to the cells); (5) during the peak period, the palisade cells are much more elongated and slender and thus more unstable under buckling compressive-type loads than shorter wider columns. The long, slender configuration of the palisade cells during the peak period consequently renders them more amenable to rupture; after this period, diametric cell expansion in the leaf seems to predominate, and a more stable configuration is obtained; (6) the rapid loss of moisture from leaves (especially younger leaves), once they are harvested, has adverse effects on rupture considerations. The loss of moisture causes protoplasm to withdraw from the cell walls, which lose their rigidity, and the cells can then withstand larger deformations without rupturing. This imposes limitations on the elapsed

Table 6. Rate of return on investment for PRO-XAN system IV operating on a 180-day season.

	Plant capacity (t green-chop forage/h)		
	20	40	80
Sales of dehydrated press cake ($US)	1 408 608	2 817 469	5 635 023
Sales of leaf concentrate ($US)	718 209	1 435 491	2 870 982
Total sales	2 126 817	4 252 960	8 506 005
Annual costs (fixed + variable) ($US)	546 164	1 247 167	2 806 274
Total investment ($US)	1 426 397	2 572 772	4 334 295
Rate of return (%)	38.3	48.5	64.7

time between harvesting and processing; and (7) the greatest fraction of leaf-protein is found in the palisade tissue (a greater number of chloroplasts, for instance), which renders the spongy tissue to secondary importance as compared with the palisades in determining the optimum period for harvesting and processing.

Recent economic research by the U.S. Department of Agriculture (Vosloh et al. 1976) demonstrated that leaf protein concentrates offer new investment opportunities (Table 6).

Discussion Conclusions

• Considerable evidence now exists to show that cassava products can, to a large degree, be successfully used as substitutes for certain cereals in nutritionally balanced rations for different species of livestock in both tropical and temperate countries.

• It is, however, difficult to define precisely what are the optimum levels of cassava that can be used and to draw more than very general conclusions from the results of many feeding trials reported in the literature. Few authors have carefully recorded the type of cassava that was fed, especially with respect to its physical nature and its cyanide content. The widespread use of the terms 'bitter' and 'sweet' is particularly misleading in terms of actual cyanide content because they represent no more than points in a continuous spectrum. Nevertheless it appears likely that the cyanide level, although rarely quantified as such, may be largely responsible for the conflicting findings of experimental trials.

• Differences in species response may also be significant. Unfortunately the most detailed research in relation to dietary cyanide content has been carried out with small laboratory animals and the results of this work may be of limited relevance to farm livestock.

• It is not possible to draw more than general conclusions from the results of the many trials concerned with feeding cassava products to poultry. This is probably due to variations in both the chemical (especially HCN) composition of the product and the processing method to which it has been subjected. Incorporation of high levels of cassava into the rations appears to be more acceptable for broilers than layers where egg production and quality are particularly susceptible to the types of imbalance that are associated with high cassava diets.

• In the case of swine rations it appears that, by supplementing the diet with appropriate nutrients, it is possible to practice life-cycle feeding using high levels of cassava. Nevertheless, there appears to be a need for further study of the impact of this practice on reproductive performance.

• The issue of supplementing cassava-based diets to assure a nutrient balance appropriate to the species and class of livestock is one of fundamental importance. The nature and extent of supplementation required also varies with the plane of nutrition, production intensity, climatic conditions, and the physical nature of the diet. It is also related to the other dietary components.

• The physical properties of a cassava-based diet are also of importance in terms of pallatability and feed consumption. With both poultry and swine, feed intake and growth rate respond favourably to pelletization although these responses can also be achieved by adding molasses, fat, or water (liquid feeding in swine) in order to eliminate the powdery characteristic of cassava-based rations. Such additions are, however, sometimes less economic than pelleting.

• The physical nature of the diet is of importance for a second reason. There appears to be a need for a revision of traditional feeding standards to take account of the fact that for mature animals in the tropics (ruminants in particular), it is more appropriate to express the concentration of feed energy in terms of density (Kcal/litre) rather than in weight units (Kcal/kg). In such circumstances the pelleting of cassava feeds is of particular importance in increasing their intake level.

• Significant advances have been made in pelleting technology in recent years but care needs to be exercised in terms of temperature control to prevent the promotion of the Maillard reaction (caramelization) especially in cassava pellets. Pelleting may also make adulteration more difficult to detect as is apparent from the high fibre and ash (silica) content of many shipments of cassava pellets exported from Southeast Asia.

• A number of workers have obtained improvements in weight gains in monogastric animals when cassava-based diets were supplemented with methionine. It

has been suggested that such supplementation fulfills two functions. First, methionine, which is most likely to be the first limiting amino acid in cassava-based diets, is of particular importance as a methyl group donor. Second it appears to be an important sulfur donor in the detoxification of the cyanide radical to thiocyanate. However, there is evidence to indicate that inorganic sulfur can, partially, substitute for methionine in the detoxification process. It was suggested that in many developing countries it would be more economical to provide methionine through alternate dietary protein sources rather than by supplementation with synthetic methionine. Thus the need and nature of methionine supplementation should be considered within the context of the balance of the ration as a whole.

- There are limited data regarding the need for methionine supplementation for cassava-based ruminant rations. The cyanide content of fresh cassava leaves appears to have no adverse effects on large ruminants although there is evidence that this is not the case in small and young ruminants. In older cattle, methionine supplementation has been reported to improve crude fibre digestibility but this has not been related to cyanide intake.
- Because cassava roots are low in protein content, special care is needed when they are used to ensure that a suitable energy to protein ratio is maintained. Apart from the possible specific need of methionine for detoxification the other essential amino acids must be provided in a balanced form. The protein supplement in a high-cassava ration should also be low in fibre and ash, especially for monogastrics, to compensate for the levels of these components in cassava root products.
- Nonprotein nitrogen (NPN) compounds can partially serve as important sources of protein in cassava-based ruminant diets. When urea is the NPN component in such diets the urea appears to be particularly well utilized for amino acid synthesis because of the similarity in timing of the release in the rumen of the energy from cassava and the nitrogen from the urea.
- Cassava-based diets may be deficient in essential fatty acids and to some extent fat supplementation is important to correct this deficiency, especially in laying rations where the need for essential fatty acids is greater than in rations for other farm animals. Fat supplementation also enhances the pelleting process and facilitates the transport and absorption of lipotropic vitamins providing the fat carrier is properly stabilized.
- Because cassava starch is higher in amylopectin and lower in amylose than corn starch, it is less readily digested by monogastrics and, presumably, by poultry. The practical importance of this is not clear nor does there seem to be knowledge of the pattern of amylotic activity in the rumen nor of the effects of processing cassava on its carbohydrate structure. It should be possible to alter the amylose:amylopectin ratio by a plant breeding program, but the justification for this is questionable.
- Mineral supplementation of high-cassava diets may be necessary, not only to compensate for the low level of most minerals in the roots, but also to offset excessive quantities of added calcium and phytic acid (resulting from adulteration), which interfere with the absorption and utilization of certain trace elements, especially zinc. Copper, iron, and iodine supplementation may also give beneficial results.
- Vitamins are usually limiting factors in cassava-based diets and may need to be added to pig and poultry rations in larger quantities than is the case for 'cereal-based diets.' The lipotropic factors (choline and inositol) may play a significant role in methionine metabolism.
- Cassava root products are deficient in xanthophylls (carotenoids) and require supplementation with these compounds when used in broiler and layer rations.
- Until very recently the agronomic aspects of producing cassava foliage for animal feed were virtually ignored. Recent work has indicated that there are distinct possibilities in treating cassava as two distinct crops with the roots rich in

energy and the foliage rich in protein and pigments. It also appears that the same plant can be used to produce several cuttings of leaves prior to harvesting, which would naturally result in a reduced yield of roots.

• The prospects for using both cassava leaves and roots in ruminant diets appear to be promising, but more information is needed on the feeding value of both products. Little is known about the digestion and utilization of cassava both in the rumen and in the subsequent digestive tract, or about the influence of cassava on the utilization of other dietary products including proteins, although cassava starch is known to be a good vehicle for promoting microbial synthesis using NPN.

• There is an urgent need to develop packages of recommended technology for cassava foliage production; such packages need to include appropriate information on the choice of variety, plant population, and agronomic and fertilizer practices. The opportunities for mechanizing planting and harvesting appear promising.

• Preliminary work conducted at CIAT has shown that by harvesting cassava at 90 days and then at 70-day intervals it is possible to produce a product that is 52% leaf with a leaf crude protein content of 29% and an overall foliage crude protein level of over 20% on a dry matter basis. In a 1-year trial, total production per hectare was 20 tonnes of dry matter and 4.0 tonnes of crude protein. In a ration in which 28% of the intake was cassava foliage, which provided 80% of the ration protein, yearling steers gained 621 grams a day. In a separate experiment in which cassava root meal provided essentially all the energy and 50% of the dietary nitrogen was NPN (urea), 18-month-old steers gained 680 grams a day during a 7-month feeding period.

• The fact that over 3 million tonnes a year of dried pelleted cassava root is shipped from Southeast Asia to Europe, where it is used as an energy source in compound pig and poultry feeds, suggests an enormous latent potential for a similar use in tropical cassava-producing countries. In addition, the potential for using cassava roots and foliage in ruminant feeding in the tropics remains largely unexplored. In Venezuela it has proven possible to produce protein from cassava leaf meal at only one fifth of the cost of protein derived from alfalfa leaf meal. It appears that in looking at the rationale for using cassava roots or foliage for animal feed it would be productive to express the potential, not in terms of crop yield, but in terms of the tonnage of meat per unit of land under cassava.

• The use of a cassava substrate for the production of single-cell protein, destined for use as an animal feed, appears to have considerable potential. A simple self-aspirating fermentor built at the University of Guelph and currently undergoing pilot plant trials at CIAT in Colombia shows considerable promise and utilizes a system that does not require sterilization, continuous heating, or the addition of specific amylotic agents. With the microorganisms being used it has proved possible to obtain a yield equivalent to 52% of the dry matter in the cassava substrate and, with the addition of urea, sulfuric acid, and phosphate, to produce a product with a 37% crude protein content.

• Before any cassava fermentation is put into commercial application the whole philosophy of using single-cell protein produced from cassava for animal feeding needs to be critically examined with respect to its economic implications, its applicability in developing countries, and its safety both to the stock eating the product and to the people engaged in the production process.

• The economic implications that require further study involve the raw material, the end product, and the production process. With respect to the raw material it is necessary to ascertain whether cassava is the most economic carbohydrate source for this type of process. The age, growing conditions, and variety of the cassava used are of relevance in terms of the sugar content of the tuber because this could strongly influence the rate and degree of fermentation. The end product needs to be compared with protein derived from conventional sources in terms of

cost and biological value. The feasibility and the economic merit of replacing the current system by a series of smaller fermentors, or by a continuous fermentation process, need further investigation in view of their attractiveness in simulation studies. Most of these economic parameters are currently being examined although the technology is too new to offer valid data.

- It is also not yet possible to offer firm recommendations regarding the applicability of this process in developing countries at either the fermentor unit or the product user level. Care will need to be exercised to ensure that rations containing the fermented biomass are appropriately balanced especially with respect to fibre content.
- Considerable efforts are being devoted to ensuring that the microorganisms used at the University of Guelph do not present a safety hazard. Extensive tissue analysis has failed to indicate any pathological changes in rats fed the biomass produced by any of the three most promising cultures (*Aspergillus fumigatus* I-21, *Rhizopus chinensis* 180, and *Cephalosporium eichhorniae* 152). However, it is well recognized that massive exposure to *A. fumigatus* spores does infect humans, and pneumonia attributable to infection by hyphal filaments of other fungi has recently been recorded. *R. chinensis* is not known to cause infection in man although other *Rhizopus* species can do so. *C. eichhorniae* 152 is unlikely to cause human infection because it only grows at a low pH; however, its growth rate is less than that of the other two cultures. Efforts are being made to develop nonsporulating and 37 °C sensitive mutants of *Aspergillus* I-21 in order to eliminate the safety hazard. A nonrevertible asporogenous mutant of *Aspergillus* (I-21A) has been developed and produces even better yields than the parent strain, but hyphal fragments might still be a biohazard. Mutants unable to grow at body temperature but which grow normally at the high fermentation temperatures have been obtained, but those isolated so far are capable of backmutating. Work on this problem is still under way.
- There are a large number of promising fields for further research in cassava root and foliage production; many of these are highlighted in the Workshop papers. Apart, however, from purely technical issues there are a number of research priorities in this field that relate specifically to economic development in cassava producing countries. These include: the justification for growing cassava rather than other crops in areas subjected to high levels of stress; the comparative advantage of using cassava for a given animal species in a specific location; the level of processing technology that is feasible in given circumstances in relation to whether the product is likely to be destined for the local or the export feed market; the prospects for the strategic use of cassava in certain parts of the life cycles of different species of livestock; and the need to establish market standards for cassava products.
- Bearing in mind the promising prospects for cassava-based diets and the wide range of opportunities for further research in this field the importance of working with properly balanced rations and of carefully recording the chemical analysis of the cassava material being used cannot be overemphasized.

Bibliography

Addy, T. O., Whitney, L. F., Davis, E. L., and Chen, C. S. (Undated) Structural parameters. In Cell rupture for leaf-protein extraction. Paper no. 1045. Amherst, Massachusetts, Mass. Agric. Exp. Stn., University of Massachusetts at Amherst.

Adegbola, A. A. 1977. Methionine as an additive to cassava based diets. In Nestel, B., and Graham, M., ed., Cassava as animal feed: proceedings of a workshop held at the University of Guelph, 18–20 April 1977. Ottawa, International Development Research Centre, IDRC-095e, 9–17.

Adrian, J., and Peyrot, F. 1971. Possible use of the cassava leaf (*Manihot utilissima*) in human nutrition. Plant Foods Hum. Nutr. 2(2), 61–65.

Adrian, J., Peyrot, F., Olivera, J. S., de Carvalho, M. F. 1969. Nutritional study on cassava leaf (*Manihot utilissima*). Rev. Cienc. Agron. (Lourenço Marques), Ser. A, 2(1), 43–49.

Agudu, E. W. 1972. Preliminary investigation on some unusual feedstuffs as yolk pigmenters in Ghana. Ghana J. Agric. Sci. 5, 33–38.

Ahmad, M. I. 1973. Potential fodder and tuber yields of two varieties of tapioca. Malays. Agric. J. 49, 166–174.

Ahmed, E. F., and Kay, M. 1975. A note on the value of molasses and tapioca as energy supplements to forage for growing steers. Anim. Prod. 21, 191–194.

Aiba, S., Humphrey, A. E., and Mills, N. F. 1973. Biochemical engineering. London, New York, Academic Press Inc.

Akinrele, I. A. 1964. Fermentation of cassava. J. Sci. Food Agric. 15, 589–594.

1967. Nutrient enrichment of gari. West Afr. J. Biol. Appl. Chem. 10, 19–23.

Alba, J. de. 1954. Valor nutritivo de la cáscara de cacao para produccion de leche en comparación con maíze molido y harina de yuca. Turrialba, 4(1), 29–34.

Albuquerque, de M. 1971. Estado atual das pesquisas com mandioca no IPEAN. In Runiao de Comissano Nacional de Mandioca, 5a, Sete Lagos, Minas Gerain, Brazil.

Alexander, J. C. 1977. Nutrition of laboratory animals with fungi grown on cassava. In Nestel, B., and Graham, M., ed., Cassava as animal feed: proceedings of a workshop held at the University of Guelph, 18–20 April 1977. Ottawa, International Development Research Centre, IDRC-095e, 85–90.

Anderson, C., Longton, J., Maddix, C., Scammell, G. W., and Solomons, G. L. 1975. The growth of microfungi on carbohydrates. In Tannenbaum, S. R., Wang, D. I. C., ed., Single-cell protein 11. Cambridge, Mass., USA, The M.I.T. Press, 314–329.

Ankrah, E. K. 1972. Riboflavin content of some fermented foods of Ghana. Ghana J. Agric. Sci. 5(2), 95–98.

Annison, E. F., Chalmers, M. I., Marshall, B. M., and Synge, R. L. M. 1964. Ruminal ammonia in relation to protein requirements of sheep. 3. Ruminal ammonia formation with various diets. J. Agric. Sci. 44, 270–273.

Anonymous. 1968. The markets for Manoic as a raw material for the manufacture of compound animal feeding stuffs in The Federal Republic of Germany, The Netherlands, and Belgium. Int. Trade Centre UNCTAD-GATT FS 21.

1970. Fortified cassava. World Farming, 12(12), 36.

Armas, A. B., and Chicco, C. F. 1973. Evaluación de la harina de yuca (*Manihot esculenta*) en raciones para pollos de engorde. Agron. Trop. (*Maracay*), 23(6), 593–599.

Arrington, L. R., Santa-Cruz, R. A., Harms, R. H., and Wilson, H. R. 1967. Effects of excess dietary iodine upon pullets and laying hens. J. Nutr. 92, 325–330.

Assia, F. de P. 1962. Efeitos da administração de raízes e tubérculos, como suplemento de inverno, na alimentação de vacas em lactação. Bol. Indust. Anim. 20, 55–61.

Auld, S. J. M. 1912. The formation of prussic acid from linseed cake and other feeding stuffs. J. Board Agric. 19, 446–460.

Aumaitre, A. 1969. Valeur alimentaire du manioc et de différents cereales dans les régimes de sevrage précoce du porcelet: utilisation digestive de l'aliment et effet sur la croissance des animaux. Ann. Zootech. 18(4), 385–398.

1972. Le manioc convient-il aux porcs? In La Revue de l'Elevage, 27.

Azi, F. A. 1976. Development of process kinetics in the manufacture of microbial protein and scale-up of an unconventional microbial reactor. Ph.D. thesis, University of Guelph, Guelph, Canada, July 1976.

Azi, F. A., Meiering, A. G., Duitschaever, C. L., and Reade, A. E. 1975. Air injection of self-aspirating impeller in aerobic fermentations. J. Milk Food Technol. 38, 94–99.

Babatunde, G. M., Fetuga, B. L., and Kassim, E. 1976. Methionine supplementation of low protein diets for broiler chicks in the tropics. Br. Poult. Sci. 17, 463–469.

Bailey, K. V. 1961. Rural nutrition studies in Indonesia. 3. Epidemiology of hunger edema in the cassava areas. Trop. Geogr. Med. 13, 289.

Baker, D. H., Clausing, W. H., Harmon, B. G., Jensen, A. H., and Becker, D. E. 1969. Replacement value of cystine for methionine for the young pig. J. Anim. Sci. 29, 581–584.

Ballantyne, B., Boardman, S. P., Bright, J., Coffee, D. J., Webber, T. D., and Williams, P. 1972.

Tissue cyanide concentrations and cytochrome oxidase activities in experimental cyanide poisoning. Br. J. Pharmacol. 44, 382–383.

Bangham, W. N. 1950a. A mandioca supera a alfalfa. Fezenda, 45(8), 27–29.

1950b. La yuca reemplaza la alfalfa. Hacienda, 45, 31–33.

Barbosa, A. S. et al. 1957. A Raspa de mandioca como substituto dos subprodutos de trigo no crescimento de suinos. Arq. Esc. Sup. Vet. (Brazil), 10, 15–24.

Barrett, M. D. P., Alexander, J. C., and Hill, D. C. 1977a. Utilization of ^{35}S from radioactive methionine or sulfate in the detoxification of cyanide by rats. Nutr. Metab. (in press).

Barrett, M. D. P., Hill, D. C., Alexander, J. C., and Zitnak, A. 1977b. Fate of orally dosed linamarin in the rat. Can. J. Physiol. Pharmacol. (in press).

Barrios, E. A., and Bressani, R. 1967. Composicíon química de la raíz y de la hojas de algunas variedades de yuca Manihot. Turrialba, 17(3), 314–320.

Barrteria, M. 1968. Cassava makes milk cheaper. Correio Zootec. 9, 147.

Becker, D. E., Jensen, A. H., Terrill, S. W., and Norton, H. W. 1955. The methionine-cystine need of the young pig. J. Anim. Sci. 14, 1086–1094.

Belasco, I. J. 1956. The role of carbohydrates in urea utilization, cellulose digestion and fatty acid formation. J. Anim. Sci. 15, 496–508.

Bermudez, L. A. 1973. Leguminosas expontáneas de posible valor forrajerc en Colombia. Bogota, Inst. Colomb., Agropecu., Bol. Técn. 21, 129p.

Berry, T. H., Combs, G. E., Wallace, H. D., and Robbins, R. C. 1966. Responses of the growing pig to alterations in the amino acids pattern of isolated soybean protein. J. Anim. Sci. 25, 722–728.

Beuving, G. 1970. Oxygen uptake in the shell gland of laying hens. Poult. Sci. 50, 758–760.

Blakley, R. L., and Coop, I. E. 1949. The metabolism and toxicity of cyanides and cyanogenetic glycosides in sheep. II. Detoxification of hydrocyanic acid. N.Z. J. Sci. Technol. 31(3)A, 1–16.

Boshell, J. 1968. Annual Report (appendix). Belem, Brazil, Belem Birus Laboratory.

Boxer, G. E., and Rickards, J. C. 1952. Studies on the metabolism of the carbon of cyanide and thiocyanate. Arch. Biochem. 39, 7–26.

Braekkan, O., Njaa, L. R., and Utne, F. 1957. The effect of cyanide on liver reserves of vitamin B_{12}. Acta Pharmacol. (Kbh.), 13, 228–232.

Bressani, R. 1968. Use of yeast in human foods. In Mateles, R. I., and Tannenbaum, S. R., ed., Single-cell protein. Cambridge, Mass., USA, The M.I.T. Press.

Broder, G., and Weil, M. H. 1964. Excess lactate: an index of reversibility of shock in human patients. Science, 143, 1457–1459.

Brook, E. J., Stanton, W. R., and Wallbridge, A. 1969. Fermentation methods for protein enrichment of cassava. Biotechnol. Bioeng. 11, 1271–1284.

Brouwer, E. 1933. Feeding test with tapioca meal on milk cows. 1931 Annual Report, 29–31.

Bruijn, G. H. de. 1973. The cyanogenetic character of cassava. (*Manihot esculenta*). In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 43–48.

Buitrago, J. A. 1964. Utilización de la yuca en dietas para crecimiento y ceba de cerdos. Tesis Med. Vet. Bogotá, Universidad Nacional de Colombia, Bogotá, Colombia, 114p.

Busson, F., and Bergeret, B. 1958. Contribution a l'étude chimique des feuilles de manioc. Méd. Trop. (Paris), 142–144.

Butler, W. G., Flux, D. S., Peterson, G. B., Wright, E. W., Glenday, A. C., and Johnson, J. M. 1957. Goitrogenic effect of white clover (*Trifolium repens* L). N.Z. J. Sci. Technol. Sect. A, 38, 793–802.

Butterworth, W. H. 1967. The digestibility of tropical grasses. Nutr. Abstr. Rev. 37(2), 349–368.

Cardoso, R. M., Campos, J., Hill, D. H., and Coelho, J. F. de Silva. 1968. Efeito de substituição gradativa do milho pela raspa de mandioca, na produção de leite. Rev. Ceres, 14(82), 308–330.

Carmody, A. 1900. Prussic acid in sweet cassava. Lancet ii, 736–737.

Carvalho, J. P. de, Monteiro, E. de S., and Soares, L. M. 1969. Feijão macacar e raspa de mandipoca em substituição ao farelo de trigo nas racoes de frangos de corte. In Brasil, Instituto de Pesquisas Agronomicas de Pernambuco. Boletim Tecnico no. 39, 14p.

Castillo, L. S., Aglibut, F. B., Javier, T. A., Gerpacio, A. L., Puyuoan, R. B., and Ramin, B. B. 1964. Camote and cassava tuber silage as replacement for corn in swine growing-fattening rations. Philipp. Agric. 47(9–10), 460–474.

Chadha, Y. R. 1961. Sources of starch in Commonwealth territories. III. Cassava. Trop. Sci. 3, 101–113.

Chalupa, W. 1975. Procedures for maximizing the utilization of proteins and amino acids by ruminants. In Proceedings of the 1975 Georgia Nutrition Conference for Feed Industry, Feb. 19–21, 142–154.

Charavanapavan, C. 1944. Studies in manioca and lima beans with special reference to their utilization as harmless food. Trop. Agri. 100, 164–168.

Chicco, C. F., Carnevalia, A. A., Shultz, T. A., Shultz, E., and Ammerman, C. B. 1971. Yuca y

melaza en la utilización de la úrea en corderos. Memorias. Assoc. Latin. Prod. Anim. 6, 7–17.

Chicco, C. F., Garbati, S. T., Müller-Haye, B., and Vecchionacce, H. I. 1972. La harina de yuca en el engorde de cerdos. Rev. Agron. Trop. 12, 599.

Chick, E. W., Balows, A., and Furcolow, M. L. (Editors). 1975. Opportunistic fungal infections. Springfield, Ill., USA, Charles C. Thomas Publisher, 359p.

Chou, K. C., and Müller, Z. 1972. Complete substitution of maize by tapioca in broiler rations. In Australasian poultry science convention, Auckland, 1972: proceedings. New Zealand, world's poultry science association, 149–160.

Chou, K. C., Nah, K. C., and Müller, Z. 1973. Replacement of maize by high level of tapioca meal in rations for growing-finishing pigs. Kajian Vet. 5, 3–10.

Church, B. D., Nash, H. A., and Brosz, W. 1972. Use of *Fungi imperfecti* in treating food processing wastes. Dev. Ind. Microbiol. 13, 30–46.

CIAT 1972. Swine production systems. 1972 Annual Report. CIAT, Cali, Colombia, 84.

1973a. Swine production systems. 1973 Annual Report. CIAT, Cali, Colombia, 121.

1973b. Cassava production systems: Forage production. 1973 Annual Report. CIAT, Cali, Colombia, 70.

1974. Swine production systems. 1974 Annual Report. CIAT, Cali, Colombia, 154.

1975a. Swine production systems. 1975 Annual Report. CIAT, Cali, Colombia, D-1.

1975b. Cassava production systems. 1975 Annual Report. CIAT, Cali, Colombia.

1976. Cassava production systems. 1976 Annual Report. CIAT, Cali, Colombia.

Clarke, E. M. W., Ellinger, G. M., and Phillipson, A. T. 1966. The influence of diet on the nitrogenous components passing the duodenum and through the lower ileum of sheep. Proc. R. Soc. Ser. B, 166, 63–74.

Clary, J. J., Mitchell, G. E., Jr., and Little, C. O. 1967a. Adaptation of sheep pancreatic secretion to dietary change. J. Anim. Sci. 26, 917 (abstr.).

1967b. Action of cattle, sheep and swine amylases on various starches. Ky. Agric. Exp. Stn. Prog. Rep. 170, 24.

Clary, J. J., Mitchell, G. E., Jr., Little, C. O., and Bradley, N. W. 1966. Dietary influence on bovine pancreatic amylase. J. Anim. Sci. 25, 899 (abstr.).

Close, J., Adriaens, E. L., Moore, S., and Bigwood, E. J. 1953. Composition en acides, aminés d'hydrolysts de farine de manioc roui, variété améré. Bull. Soc. Chim. Biol. (Brussels), 35(9), 985–993.

Conceiçao, A. J. da, Sampaio, C. V., and Mendés, M. A. 1973. Competição de variedades de aipim e mandioca para forragem. Univ. Federal, Bahia (Projeto Mandioca), 130–142.

Collard, P., and Levi, S. 1959. A two stage fermentation of cassava. Nature (Lond.), 183, 620–621.

Conn, E. E. 1969. Cyanogenic glycosides. Agric. Food Chem. 17(3), 519–526.

Cossettes, L. 1921. Et la farine de manioc "Nosybeene" dans l'alimentation des animaux. Bull. Econ. Madagascar, 3, 293–296.

Couch, J. R., Olcese, O., Sanders, B. G., and Halick, J. V. 1950. Vitamin B_{12}, APF concentrates, dried whey, fish solubles and liver fractions "L" in the nutrition of the mature fowl. J. Nutr. 42, 473–485.

Coursey, D. G. 1973. Cassava as food: toxicity and technology. In Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 27–36.

Coursey, D. G., and Halliday, D. 1974. Cassava as animal feed. Outlook Agric. 8, 273.

Coursey, D. G., and Haynes, P. H. 1970. Root crops and their potential as food in the tropics. World Crops, 22, 261–265.

Cromwell, G. L., Sihombing, D. J. H., and Hays, V. W. 1975. Effects of iodine level on performance and thyroid traits of growing pigs. J. Anim. Sci. 41, 813–818.

De Brochard, P., Rickard, J. R., and Triaca, H. 1957. Table international de composition des aliments. Marseilles.

De Bruijn, G. H. 1973. The cyanogenic character of cassava (*Manihot esculenta*). In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 43–48.

Delange, F., van der Velden, M., and Ermans, A. M. 1973. Evidence of an antithyroid action of cassava in man and animals. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings interdisciplinary workshop, London, England. Ottawa, International Development Research Centre, IDRC-010e, 147–151.

Devendra, C. 1963. A comparison of two systems of pig feeding commonly used in Malaya. Malay. Agric. J. 44(1), 26–41.

1975. Efficient utilisation of feedingstuffs in Malaysia: perspectives and potential prospects. Proceedings of the seminar on livestock products and the food crisis. Bulletin no. 141, Ministry of Agriculture, Malaysia, 18–32.

1976a. The utilisation of agro-industrial by-products in Asia and the Far East. Rome, Italy, FAO Technical Consultation on New Feed Resources, 22–24 November 1976. (Mimeograph, 48p.)

1976b. Studies on the utilisation of rice straw by sheep. IV. Effect of carbohydrate source on

the utilisation of dietary urea and nitrogen retention. Malays. Agric. J. 50, 358–370.

1977. Studies on the utilisation of cassava (*Manihot esculenta* Crantz) in sheep, MARDI Res. Bull. (in press).

Devendra, C., and Hew, V. F. 1977. The utilisation of varying levels of dietary palm oil by growing-finishing pigs. MARDI Res. Bull. (in press).

Devendra, C., and Lee Kok Choo, T. 1975. Studies on Kedah-Kelantan cattle. I. The effect of improved nutrition on growth. MARDI Res. Bull. 3, 68–86.

1976a. Studies on Kedah-Kelantan cattle. II. The effect of feeding increasing levels of tapioca (*Manihot utilissima* Pohl). MARDI Res. Bull. 4, 80–89.

1976b. Studies on Kedah-Kelantan cattle. III. Body characteristics and carcass composition. MARDI Res. Bull. 4, 81–88.

Devendra, C., and Sivarajasingam, S. 1975. A preliminary study on the growth response of Local Indian Dairy (LID) calves. MARDI Rep. no. 39, 12p.

Echandi, O. 1952. Valor de la harina de hojas y tallos deshidratados de yuca en la producción de leche. Turrialba, 2(4), 166–169.

Edwards, H. M., Jr. 1966. The effect of protein source in the diet on Zn^{65} absorption and excretion by chickens. Poult. Sci. 45, 412.

Eggum, B. O. 1968. Aminosyrekoncentration eg proteinkualitet. Kobenhayn Stoergaards Forlag, 76.

1970. The protein quality of cassava leaves. Br. J. Nutr. 24(3), 761–768.

Ehrlich, P. R., and Ehrlich, A. H. 1970. Population resources environment. San Francisco, Calif., USA, Freeman Co.

Ekpechi, O. L. 1967. Pathogenesis of endemic goitre in eastern Nigeria. Br. J. Nutr. 21, 537.

1973. Endemic goitre and high cassava diets in eastern Nigeria. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 139–145.

Ekpechi, O. L., Dimitriadou, A., and Fraser, R. 1966. Goitrogenic activity of cassava (A staple Nigerian food). Nature (Lond.), 210, 1137–1138.

El-Boushy, A. R., Simons, P. C. M., and Wiertz, G. 1968. Structure and ultrastructure of the hen's egg shell as influenced by environmental temperature, humidity and vitamin C additions. Poult. Sci. 47, 456–467.

El Jack, M. H., and Lake, P. E. 1967. The content of the principal inorganic ions and carbon dioxide in the uterine fluids of the domestic hen. J. Reprod. Fertil. 13, 127–132.

Elliott, R. C., French, C. H., and Folkerston, K. 1961. Protein biological values for beef cattle. 1. The influence of protein source and starch additions. Rhod. Agric. J. 58, 131–135.

Emmons, C. W., Binford, C. H., and Utz, J. P. 1970. Medical mycology. Philadelphia, Penn., USA, Lean & Febiger, 508p.

Enriquez, F. Q., and Ross, E. 1967. The value of cassava root meal for chicks. Poult. Sci. 46, 622–626.

1972. Cassava root meal in grower and layer diets. Poult. Sci. 51, 228–232.

Ermans, A. M., Thilly, C., Vis, H. L., and Delange, F. 1969. Permissive nature of iodine deficiency in the development of endemic goiter. In Stanbury, J. B., ed., Endemic goiter. Washington, D.C., Pan American Health Organization.

Ermans, A. M., van der Velden, M., Kinthaert, J., and Delange, F. 1973. Mechanism of the goitrogenic action of cassava. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 153–157.

Eshiett, N., and Ademosun, A. A. 1976. Cassava for poultry, progress report on the use of cassava as animal feed in Nigeria. Ottawa, submitted to IDRC.

Estima, A. L. et al. 1967. Melaco, mandioca e farelo de algodão como supplementos para olho de cana fresco ou ensildo. Pesqui. Agropecu. Bras. 2, 411–420.

Ewing, R. A. 1963. Poultry nutrition, 5th ed. Calif., USA, The Ray Ewing, Publishing Co.

Falanghe, O. 1949. Substituicão dos farelos de trigo por farelos de arroz e mandioca na alimentacao de poedeiras. Biologico, 15, 35–38.

Fangauf, R. 1955. Tapiokamhi im futter von legehühnern. Futter and Futtering, 53, 426.

FAO 1973. Production yearbook 1973, Vol. 27. Rome, Italy, FAO.

1974. Production yearbook 1974. Vol. 28. Rome, Italy, FAO.

1975. Production yearbook 1975. Vol. 29. Rome, Italy, FAO.

Ferreira, J. J., Silva, J. F. da, and Gomide, J. A. 1974. Efeito do estadio de desenvolvimento, do emurchecimento e da adiçao de raspa de mandioca sobre o valor nutritivo da silegem de capim-elephante (*Pennisetum purpureum* Schum). Experientiae, 17(5), 85–108.

Ferrer, A. 1970. La yuca una riqueza ignorada. Agric. Venez. 97, 56–58.

Fraser, D. M. K. 1973. Manioc unsuitable for turkeys. Vet. Rec. 93, 238.

French, M. H. 1937. The nutritive value of cassava roots and the nutritive value of cowpea seed. Tanganyika department of veterinary science and animal husbandry annual report, 81–85.

Gadelha, J. A., Campos, J., and Mayrose, V. 1969. Farelo de raspa de mandioca na alimentação de pintos. Experientiae, 9(4), 111–132.

Göhl, B. 1975. Tropical feeds, Rome, Italy, FAO.

Gómez, G., Camacho, C., and Maner, J. H. 1976. Utilización de yuca fresca y harina de yuca en alimentación porcina. In Memoria del Seminario Intern. de Ganadería Tropical, Acapulco, México, 8–12 Marzo 1976, 91–92.

1977. Utilization of cassava-based diets in swine feeding. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the fourth symposium of the international society for tropical root crops: centro internacional de agricultura tropical, CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 262–266.

Gondwe, A. T. D. 1974. Studies on the hydrocyanic acid contents of some local varieties of cassava (*Manihot esculenta* Crantz) and some traditional cassava food products. East Afr. Agric. For. J. 40(2), 161–167.

Gontijo, R. M., Vivela, H., Carneiro, G. G., Vidgal, G. T., and Miranda, J. J. F. 1972. Estudo comparativo entre raspa de mandioca lavada et milho desintegrado como fontes de energia, para engorda de novilhos azebuados em contimamento. Arq. Esc. Vet. 24(1), 27–31.

Grace, M. 1971. Cassava processing. Food and agriculture organization of the United Nations, Rome, 11.

Gramacho, D. D. 1975. Contribução ao estudo químico-tecnologico de feno da mandioca. Cruz das Almas, Brasil. Bahía, Univ. Federal, Bahía Escola de Agronomia. Brascan Nordeste Serie Pesquisa 1(1), 143–152.

Gray, F. V., Pilgrim, A. F., and Weller, R. A. 1958. The digestion of foodstuffs in the stomach of sheep and the passage of digesta through its compartments and solids. 2. Nitrogenous compounds. Br. J. Nutr. 12, 413–421.

Gray, W. D. 1970. The use of fungi as food and in food processing. CRC Crit. Rev. Food Technol. 1, 225–329.

Gray, W. D., and Abou-el-seoud, M. O. 1966. Fungal protein for food and feeds. 3. Manioc as a potential crude raw material for tropical areas. Econ. Bot. 20, 251.

Greenstreet, V. R., and Lambourne, J. 1933. Tapioca in Malaya. Bull. Dept. Agric. F.M.S. and S.S., Gen. Ser. 13.

Gregory, K. F. 1977. Cassava as a substrate for single-cell protein production: microbiological aspects. In Nestel, B., and Graham, M., ed., Cassava as animal feed: proceedings of a workshop held at Guelph, 18–20 April 1977. Ottawa, International Development Research Centre, IDRC-095e, 72–78.

Gregory, K. F., Meiering, A. G., Azi, F. A., Sedgwick, J. H. D., Cunningham, J. D., MacLean, S. J., Santos-Núñez, J., and Gómez, J. 1977. Establishment of a pilot plant for the production of fungal protein from cassava. In Cock, J., MacIntyre, R., and Graham, M., ed., proceedings of IV international symposium on tropical root crops, Cali, Colombia, August 1976. Ottawa, International Development Research Centre, IDRC-080e, 267–270.

Gregory, K. F., Reade, A. E., Khor, G. L., Alexander, J. C., Lumsden, J. H., and Losos, G. 1976. Conversion of carbohydrates to protein by high temperature fungi. Food Technol. 30(3), 30–35.

Gregory, K. F., Reade, A. E., Santos-Núñez, J., Alexander, J. C., Smith, R. E., and MacLean, S. J. 1977. Further thermotolerant fungi for the conversion of cassava starch to protein. Anim. Feed. Sci. Technol. 2, 7–19.

Guenther, E., Carison, C. W., Olson, O. O., Kohler, G. O., and Livingston, A. L. 1973. Pigmentation of egg yolks by xanthophylls from corn, marigold, alfalfa and synthetic sources. Poult. Sci. 52, 1787–1798.

Guimaraes, M. L., and Barros, M. S. C. de. 1972. Bol. Tec. Div. Tecnol. Agr. Aliment. (Brazil), 4, 4.

Guin, A., and Andonard, P. 1910. Tapioca leaves for raising calves. Bull. Soc. Natl. Agric. (France), 68, 776–779.

Gutierrez, N. A., and Anderson, P. P. 1972. La importancia relativa de frijol, maiz, arroz, yuca y carne en la zona tropical. Internat. Rep. CIAT.

Harmon, B. G., Becker, D. E., Jensen, A. H., and Norton, H. W. 1968. Effects of Na_2EDTA in diets of different iron levels on utilization of calcium, phosphorus and iron by rats. J. Anim. Sci. 27, 418–423.

Harper, A. E., Benevenga, N. J., and Wohlhueter, R. M. 1970. Effects of ingestion of disproportionate amounts of amino acids. Physiol. Rev. 50, 528–558.

Harris, L. E., and Mitchell, H. H. 1941. The value of urea in the synthesis of protein in the paunch of the ruminant. 1. Maintenance. 2. In growth. J. Nutr. 22, 167–182.

Hendershott, C. R. 1972. In A literature review and research recommendations on cassava (*Manihot esculenta* Crantz). University of Georgia, Athen, Georgia.

Henderson Research Station 1970. Department of Research and Specialist Services, Ministry of Agriculture, Salisbury, 45p.

Henke, A. 1919. Cassava meal as a feed for dairy cattle. Col. Hawaii Bull. 6, 20–21.

Henry, Y. 1971. Effects nutritionnels de l'incorporation de cellulose purifice dans le régime du porcen croissance — finition. Ann. Zootech. 19, 117.

Herrington, M. D., Elliott, R. C., and Brown, J. E. 1971. Diagnosis and treatment of thyroid dysfunction occurring in sheep fed on *Cynodon plectostachyus*. Rhod. J. Agric. Res. 9, 87–93.

Hesseltine, C. W. 1965. A millenium of fungi, food and fermentation. Mycologia, 57, 149–157.

Hew, V. F. 1975. The effect of some local carbohydrate sources such as cassava and sago on the performance and carcass characteristics of growing-finishing pigs. M. Agric. Sci., dissertation, Faculty of Agriculture, University of Malaya, Kuala Lumpur, 177p. (unpublished).

Hew, V. F., and Hutagalung, R. I. 1972. The utilization of tapioca root meal (*Manihot utilissima*) in swine feeding. Malays. Agric. Res. 1, 124–130.

1977. Utilization of cassava as a carbohydrate source for pigs. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the fourth symposium of the international society for tropical root crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 242–246.

Hilditch, T. P., and Williams, P. N. 1964. The chemical constitution of natural fats, 4th ed. London, England, Chapman & Hall Ltd.

Himmich, W. A., and Saunders, J. P. 1948. Enzymatic conversion of cyanide to thiocyanate. Am. J. Physiol. 153, 348–354.

Hinton, C. F., Fry, J. L., and Harms, R. H. 1974. Influence of xanthophyll-free pullet grower diet on subsequent egg yolk pigmentation. Poult. Sci. 53, 223–226.

Horowitz, N. H. 1947. Methionine synthesis in neurospora. The isolation of cystathione. J. Biol. Chem. 171, 225–259.

Huber, J. T., Natrajan, S., and Polan, C. E., 1967a. Adaptation to starch in steers fed by nipple pail. J. Dairy Sci. 50, 1161–1163.

Huber, J. T., Sandy, R. A., Polan, C. E., Byrant, H. T., and Blaser, R. E. 1967b. Varying levels of urea for dairy cows fed corn silage as the only forage. J. Dairy Sci. 50, 1241–1247.

Hudson, B. J. F., and Ogunsua, A. O. 1974. Lipids of cassava tubers (*Manihot esculenta* Crantz). J. Sci. Food Agric. 25(12), 1503–1508.

Hume, J. D. 1970. Synthesis of microbial protein in the rumen. 1. Response to higher volatile fatty acids. Aust. J. Agric. Res. 21, 297–304.

Hume, J. D., and Bird, P. R. 1970. Synthesis of microbial protein in the rumen. II. The effect of dietary protein. Aust. J. Agric. Res. 21, 305–314.

Humphrey, A. E. 1974. Current developments in fermentation. Chem. Eng. 81(26), 98–112.

Hurst, E. W. 1940. Experimental demyelination of the central nervous system. Aust. J. Exp. Biol. Med. Sci. 18, 201–223.

Hutagalung, R. I. 1972. Nutritive value of leaf meal, tapioca root meal, normal maize and opaque-2 maize and pineapple bran for pig and poultry. 17th Annu. Conf. Mal. Vet. Assoc., University of Malay. Dec. 1972, 1–10.

Hutagalung, R. I., and Chang, C. C. 1977a. Effects of cassava leaves supplementation on performance, egg quality and yolk cholesterol content of laying hens. Malay. Appl. Biol. 6 (in press).

Hutagalung, R. I., and Chey, T. W. 1976. Evaluation of agricultural products and by-products as animal feeds. V. Utilization of pineapple bran and stearin by chickens: proceedings of the conference on Malaysian food self-sufficiency, The Univ. of Malaya. Agric. Graduates Alumni (UMAGA), Malaysia, August 21–23, 1975, 261–272.

Hutagalung, R. I., Phuah, C. H., and Hew, V. F. 1973. The utilization of cassava tapioca (*Manihot utilissima*) in livestock feeding. Third proc. int. symp. trop. root and tuber crops, 45p.

Hutagalung, R. I., Schwarz, F. J., and Kirchgessner, M. 1977. Intestinale Aufnahme und durchtritt von zink nach zulage von 2,4-dinitrophenol und ouabain. Archiv. Tierernahrung (in press).

Hutagalung, R. J., Jalaludin, S., and Chang, C. C. 1974. Evaluation of agricultural products and by-products as animal feeds. II. Effects of levels of dietary cassava (tapioca) leaf and root on performance, digestibility and body composition of broiler chicks. Malay. Agric. Res. 3, 49–59.

Hutagalung, R. I., and Tan, P. H. 1976. Utilization of nutritionally improved cassava in poultry and pigs diet. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the fourth symposium of the international society for tropical root crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 255–263.

Instituto de Investigaciones Technologicas. 1975. Evaluación de calidad de yuca almacenada en silos de campo y en cajas con aserrín húmedo, fase analítica. Bogotà, Instituto de Investigaciones Tecnológicas, 31p.

Ingram, J., and Humphries, J. R. O. 1972. Cassava storage. A review. Trop. Sci. 14(2), 131–148.

International Institute of Tropical Agriculture. 1974. Evaluation for quality. In Root and tuber breeding. Annual Report, IITA.

Imrie, F. K. E., and Vlitos, A. J. 1975. Production of fungal protein from carob (*Ceratonia siliqua* L.). In Tannenbaum, S. R., and Wang, D. I. C., ed., Single-cell protein II. Cambridge, Mass., USA, The M.I.T. Press, 223–343.

Jalaludin, S., and Leong, S. K. 1973. Response of laying hens to low and high levels of tapioca meal. Malay. Agric. Res. 2, 47–51.

Jalaludin, S., and Yin, O. S. 1972. Hydrocyanic acid (HCN) tolerance of the hen. Malay. Agric. Res. 1, 2.

Janssen, W. M. M. A., and Terpstra, K. 1972. Feeding values of poultry. Publication of the Spelderholt Institute for Poultry Research.

Jenkins, N. K., Morris, T. R., and Valamotis, D.

1970. The effect of diet and copper supplementation on chick growth. Poult. Sci. 11, 241–248.

Jennings, D. L. 1970. Cassava in Africa. Field Crop Abstr. 23, 271–277.

Jensen, L. S., Fry, R. E., Alfred, J. B., and McGinnis, J. M. 1957. Improvement in the nutritional value of barley for chicks by enzyme supplementation. Poult. Sci. 36, 919–921.

Joachim, A. W. R., and Panditteseker, D. G. 1944. Investigation on the hydrocyanic acid content of manioc. Trop. Agric. 100, 150–163.

Job, T. A. 1975. Utilization and protein supplementation of cassava for animal feeding and the effects of sulphur sources on cyanide detoxification. Ph.D. thesis, Department of Animal Science, University of Ibadan, Nigeria.

Jacobs, H. L., and Scott, M. L. 1957. Factors mediating food and liquid intake in chickens. Poult. Sci. 36, 8.

Johnson, P. T. C., Rose, C. J., and Mills, W. R. 1968. Nutritional studies with early weaned beef calves. Rhod. J. Agric. Res. 6, 5–11.

Johnson, R., Moir, R. J., and Underwood, E. J. 1949. Sulphur containing amino acids in the rumen bacteria of sheep. Nature (Lond.), 163, 101.

Johnson, R. N., and Raymond, W. D. 1965. The chemical composition of some tropical food plants. IV. Manioc. Trop. Sci. 7(3), 109–115.

Jones, W. O. 1959. Manioc in Africa. Stanford, Calif., USA, Stanford University Press.

Joshi, R. C., and Majumdar, B. M. 1972. Urea utilisation by ruminants as affected by carbohydrate source. Indian J. Exp. Biol. 4, 231–234.

Juarez, L. 1955. Estudio agronómico sobre la utilización de la yuca como forraje. Lima, Estación Experimental Agrícola La Molina. Bol. 58.

Kaczka, E. A., Denkewal, R. G., and Folker, K. 1950. Vitamin B_{12}. XIII. Additional data on vitamin B_{12a}. J. Am. Chem. Soc. 73, 335–337.

Kadawaki, I. 1936. New compounds of urea-formaldehyde condensation products. Rep. Imp. Ind. Res. Lab., Osaka, Japan, Vol. 6, 15–41.

Kempjes, M. R., Boorman, K. N., and Lewis, D. 1970. The alleviation of methionine toxicity. University of Nottingham School of Agriculture annual report, England. 79–83.

Kare, M. R. 1965. Special senses. In Sturkie, D. D., ed., Avian physiology, 2nd ed. Ithaca, N.Y., USA, Comstock Publishing Associates.

Karr, M. R., Little, C. O., and Mitchell, G. E. 1966. Starch disappearance from different segments of the digestive tract of steers. J. Anim. Sci. 25, 654.

Karue, C. N. 1973. Metabolism of dietary urea with cassava when used to supplement dry season roughage in Kenya. III. World Conf. Anim. Prod., vol. 1, 5(c), 44–45.

Karue, C. N., Evans, J. L., and Tillman, A. D. 1973. Voluntary intake of dry matter by African Zebu cattle. Quality of feed and the reference base. J. Anim. Sci. 36(8), 1181–1185.

Kassim, H., and Jalaludin, S. 1972. The utilization of tapioca in ration for laying poultry. Malay. Agric. Res. 1, 48–53.

Kay, M., MacDearmid, A., and Massie, R. 1972. Intensive beef production. 13. Replacements of concentrates with root crops. Anim. Prod. 15, 67–73.

Ketiku, A. O., and Oyenuga, V. A., 1970. Preliminary report on the carbohydrate constituents of cassava root and yam tuber. Nigerian J. Sci. 4(1), 25–30.

Khajarern, S., Hutanuwatr, N., Khajarern, J., Kitpanit, N., Phalaraksh, K., and Terapuntuwat, S. 1977. The improvement of nutritive and economic value of cassava root products. Khon Kaen, Thailand, 1975–6 Annual report of the cassava/nutrition project, to IDRC, Department of Animal Science, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand, January 1977.

Khajarern, S., and Khajarern, J. M. 1977. Use of cassava as a food supplement for broiler chicks. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the fourth symposium of the international society for tropical root crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 246–250.

Khor, G. L. 1974. Nutritional and safety evaluations of microbial proteins grown on cassava. M.Sc. thesis, University of Guelph, Guelph, Canada.

Khor, G. L., Alexander, J. C., Lumsden, J. H., and Losos, G. J. 1977. Safety evaluation of *Aspergillus fumigatus* grown on cassava for use as an animal feed. Can. J. Comp. Med. (in press).

Khor, G. L., Alexander, J. C., Reade, A. E., Gregory, K. F., Lumsden, J. H., and Losos, G. J. 1975. Nutritional and safety evaluations of microbial proteins from cassava: proceedings of the tenth international congress on nutrition, Kyoto, Japan. (Abstr. 5407.)

Khor, G. L., Alexander, J. C., Santos-Núñez, J., Reade, A. E., and Gregory, K. F. 1976. Nutritive value of thermotolerant fungi grown on cassava. J. Inst. Can. Sci. Technol. Aliment. 9(3), 139–143.

Kihlberg, R. 1972. The microbe as a source of food. Annu. Rev. Microbiol. 26, 427–466.

Kitpanit, N. 1975. Tapioca meal versus rice-maize based diets for pigs. In Research report in the FAO postgraduate course in animal science 1974/1975. Copenhagen, Denmark, Veterinary Faculty FAO Fellows, Royal Veterinary Agricultural University.

Klein, W., and Barlowen, von G. 1954. Tapiocamehl im aufzuchfutter Arch. Geflügelkd, 18, 415–528.

Klose, A. A., and Fevold, H. L. 1945. Nutritional

value of yeast protein to the rat and the chick. J. Nutr. 29, 421.

Knowles, E. L., and Bain, J. T. B. 1968. Chem. Ind. (Lond.) 8, 232.

Kohler, G. O., and Bickoff, E. M. 1971. Commercial production (of leaf protein) from alfalfa in the USA. In Leaf protein. Oxford, England and Edinburgh, Scotland, Blackwell Scientific Publications Ltd.

Kolb, E. 1966. IV. Ernährungsphysiologische Bedeutung und Stoffwechsel der Kohlenhydrate in Vergleichend Ernährungslehre des Menschen und seiner Haustiere. Jena, Germany, VEB Gustav Fischer Velag, 370.

Kroening, G. H., Pond, W. G., and Loosli, J. K., 1965. Dietary methionine–cystine requirement of the baby pig as affected by threonine and protein levels. J. Anim. Sci. 24, 519–525.

Labre, S., Urdaneta, T., Yori, P., Olivares, R., and Avendano, A. 1975. Utilización de la suplementación con melaza, úrea y yuca en el crecimiento de becrros criolles limoneros. Agron. Trop. (Maracay), 25(3), 201–205.

Lang, K. 1933. Die Rhodanbeldung im Tierkorpor. Biochem. Z. 259, 243–246.

Lang, S. 1894. Arch. Exp. Pathol. Pharmakol. 36, 75.

1895. Arch. Exp. Pathol. Pharmakol. 34, 347.

Latham, M. 1965. Human nutrition in tropical Africa. Rome, Italy, Food and Agriculture Organization of the United Nations.

Lee, K. C., and Hutagalung, R. I. 1972a. Nutritional value of tapioca leaf (*Manihot utilissima*) for swine. J. Nutr. 40, 587.

1972b. Nutritional value of tapioca leaf (*Manihot utilissima*) for swine. Malay. Agric. Res. 1(1), 38–47.

Leong, S. K., and Jalaludin, S. 1973. Response of laying hens to low and high levels of tapioca meal. Malay. Agric. Res. 2, 47–51.

Lessell, S. 1971. Experimental cyanide optic neuropathy. Arch. Opthal. 84, 194–204.

Lewis, D., and McDonald, I. W. 1958. The interrelationship of individual proteins and carbohydrates during fermentation in the rumen of the sheep. II. The fermentation of casein in the presence of starch or other carbohydrate materials. J. Agric. Sci. 51, 108–118.

Lim, H. K. 1968. Composition data of feeds and concentrates. Malay. Agric. J. 46(1), 63–79.

Lira, M. B., and Fernandes, E. 1962. Bromatologia das farinhas de mandioca produzidas no Amazonas. Arq. Bras. Nutr. 18(1–2), 87–94.

1964. Bromatologia das farinhas de mandioca produzidas no Amazonas. Recife, Inst. Nac. Pesq. Amazonia, Pub. 7.

Little, C. O., Mitchell, G. E. Jr., and Reitnour, G. M. 1968. Post ruminal digestion of corn starch in steers. J. Anim. Sci. 27, 790–797.

Lofgreen, G. P. 1965. Net energy of fat and molasses for beef steers with observations. J. Anim. Sci. 24, 480–487.

Lofgreen, G. P., Loosli, J. K., and Maynard, L. A. 1947. The influence of protein source upon nitrogen retention by sheep. J. Anim. Sci. 6, 343–347.

Lofgreen, G. P., and Otagaki, K. K. The energy of blackstrap molasses for fattening steers as determined by a comparative slaughter technique. J. Anim. Sci. 19, 293–298.

Loosli, J. K., and Harris, L. E. 1945. Methionine increases the value of urea of lambs. J. Anim. Sci. 4, 435–437.

Lucas, J. E. 1914. Expérience sur l'emploi de la farine de manioc dans l'alimentation de vaches laitières. Ann. Sci. Agron. 3, 337–342.

1915. Expérience sur l'emploi de la farine de manioc dans l'alimentation de vaches laitières faite à la ferme agronomique de Gournay-sur-Marne. Bull. Econ. Madagascar, 15, 67–71.

Luyken, A. P. et al. 1968. De voedingswaarde van het eiwit van cassave blad. Zeist, Holland, Central Instituut voor Voedingsonderzoek, Rap. R. 2617.

Luyken, R., de Groot, A. P., and Stratum van P. G. C. 1961. Nutritional value of foods from New Guinea. II. Net protein utilization, digestibility and biological value of sweet potatoes, sweet potato leaves and cassava leaves from New Guinea. In Utrecht, Central Institute for Nutrition and Food Research, 18p.

Machlin, L. J., Jackson, J. T., Lankenau, A. H., and Pearson, P. B. 1954. Uptake of ^{35}S in feathers, gizzard lining, liver and muscle of young chickens after injection with radioactive methionine or sulfate. Poult. Sci. 33, 234–238.

Mahendranathan, T. 1971a. The effect of feeding tapioca (*Manihot utilissima* Pohl) leaves to pigs. Malay. Agr. J. 48, 60.

1971b. Potential of tapioca (*Manihot utilissima* Pohl) as a livestock feed. Malay. Agric. J. 48(1), 77–89.

Mallevere, M. 1914. Expérience sur l'emploi de la farine de manioc dans l'alimentation des vaches laitières. Bull. Soc. Natl. Agric. France, 74, 638–644.

Mandioca, E. 1969. Batata-doce aumentam leit na seca. Coopercotia, 19, 52.

Maner, J. 1972. Cassava in swine feeding. First Latin American Swine Seminar, 29p.

Maner, J. H. 1972. La yuca en la alimentación de cerdos. In Seminario sobre sistemas de producción de porcions en América Latina, Centro Internacional de Agricultura Tropical, CIAT, Cali, Colombia, 18–21 Septiembre 1972, 189–227.

1973. Cassava in swine feeding. In centro internacional de agricultura tropical, Cali, Colombia, Bull. RB-1.

1974. Management and feeding of pigs in the tropics. In animal production in the tropics:

proceedings of the international symposium on animal production in the tropics. Ibadan, Nigeria, Heinemann Educational Books Nigeria Ltd.

Maner, J. H., and Gómez, G. 1973. Implications of cyanide toxicity in animal feeding studies using high cassava rations. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 113–120.

Manjarrez, M. M., Fernández, C. A., Cabrera, A. R., Carretero, M. A., Avila, E., and Shimada, A. S. 1973. Valor nutritivo de una combinación de harina de yuca (*Manihot esculenta*) con puliduras de arroz como substituto del maíz en la alimentación de pollos y cerdos. In Investigaciones sobre el valor alimenticio de la yuca para los animales. Mexico, Instituto National de Investigaciones Pecuarias. Departamento de Divulgación Técnica.

Manouselis, G. 1976. Aerobic fermentation of sauerdraut waste waters by yeast. M.Sc. thesis, Department of Food Science, University of Guelph, Guelph, Canada.

Mantel, K. 1961. Effect of laying meals with different portions of cereals and the deficit of energy made up with cassava meal. Arch. Geflugelkd. 25(6), 373–382.

Maravalhas, N. 1964a. Carotenoides nas farinhas de mandioca. In Manaus, Brasil, Instituto Nacional de Pesquisas da Amazonia, pub. 6 Quimica, 39–41.

1964b. Carotenoides de *Manihot esculenta* Crantz. In Manaus, Brasil, Instituto Nacional de Pesquisas da Amazonia, pub. 6 Quimica, 35–38.

Marcano, J. 1965. Determinación del rendimiento y contenido en ácido cianhídrico de algunas variedades de yuca (*Manihot utilissima* Pohl). Jusopín, Univ. de Oriente, 15p.

Martin, F. W. 1970. Cassava in the world of tomorrow. In Proceedings of the 2nd international symposium on tropical root and tuber crops, Honolulu and Kapaa, Hawaii. Honolulu, Hawaii, University of Hawaii, 53–58.

Mashet, C. W., Kelley, K. L., Boxer, G. E., and Richards, J. C. 1952. Antidotal efficiency of vitamin B_{12} in experimental cyanide poisoning. Proc. Soc. Exp. Biol. (N.Y.), 31, 234–236.

Mathur, M. L., Sampath, S. R., and Ghosh, S. N. 1969. Studies on tapioca: effect of 50 and 100 percent replacement of oats by tapioca in the concentrate mixture of dairy cows. Indian J. Dairy Sci. 22, 193–199.

Maust, L. E., Pond, W. G., and Scott, M. L. 1972a. Energy value of a cassava–rice bran diet with and without supplemental zinc for growing pigs. J. Anim. Sci. 35, 953–957.

Maust, L. E., Scott, M. L., and Pond, W. G. 1972b. The metabolizable energy of rice bran, cassava flour, and blackeye cowpeas for growing chickens. Poult. Sci. 51, 1397–1401.

Maust, L. E., Warner, R. G., Pond, W. G., and McDowell, R. E. 1969. Rice bran–cassava meal as a carbohydrate feed for growing pigs. J. Anim. Sci. 29, 140.

McIntyre, K. H., and Williams, V. J. 1970. The effects of intravenous urea infusion on nitrogen metabolism in sheep. Aust. J. Agric. Res. 21, 95–105.

McMillan, A. M., and Dudley, F. J. 1941. Potato meal, tapioca meal and town waste in chicken rations. Harper Adams Utility Poult. J. 26(9), 191–194.

Meiering, A. G., and Azi, F. A. 1977. Fermenter performance in microbial protein production from cassava. In Nestel, B., and Graham, M., ed., Cassava as animal feed: proceedings of a workshop held at the University of Guelph, Guelph, Canada, 18–20 April 1977. Ottawa, International Development Research Centre, IDRC-095e, 79–84.

Meiering, A. G., Azi, F. A., and Gregory, K. F. 1977. Mikrobielle Eiweisserzeugung aus pfanzlichen und tierischen Kohlehydraten (microbial protein production from plant and animal carbohydrates). Paper presented for publication in Grundl. Landtechnik, February 1977.

Meister, A. 1953. Preparation and enzymic reactions of the keto anatozines of asparagine and glutamines. Fed. Proc. (U.S.), 12, 245.

Mercier, C., and Guilbot, A. 1974. Influence des conditions de granulation du maïs sur les caractéristique physico–chémiques de son amidon. Ann. Zootech. 23, 241.

Mertens, D. R. 1977. Importance and measurement of protein insolubility in ruminant diets. In Proceedings of the 1977 Georgia nutrition conference, 16–18 February 1977, 30–39.

Mesa, J., Maner, J. H., Opando, H., Portela, R., and Callo, J. T. 1970. Nutritive value of different tropical sources of energy. J. Anim. Sci. 31, 208.

Meyreles, L., and MacLeod, N. A. 1976. La yuca como fuente de proteína forrajera, efecto de la población de plantas y de la edad del corte. Santo Domingo, Centre Dominicano de Investigación Pecuaria 2a. Reunión Anual.

Miranda, de R. M., Laun, G. F., and Costa, B. L. 1957. Emprégo de feno de mandioca, de Cudzú tropical, de marmelada de cavalo e de alfalfa em rações de pintos. Rio de Janeiro, Instituto de Zootecnia, pub. 19, 18p.

Mitchell, J. R., Becker, D. E., Jensen, A. H., Harmon, B. G., and Norton, H. W. 1968. Determination of amino acid needs of the young pig by nitrogen balance and plasma-free amino acids. J. Anim. Sci. 27, 1327–1331.

Modebe, A. N. A. 1963. Preliminary trial on the value of dried cassava (*Manihot utilissima*

Pohl) for pig feeding. J. West Afr. Sci. Assoc. 7, 127–133.

Montgomery, R. D. 1969. Cyanogens. In Liener, I. E., ed., The toxic constituents of plant foodstuffs. New York, London, Academic Press Inc., 143–157.

Mohme, H., and Pfeffer, E. 1973. Briketts aus heissluftgetrocknetem gras mit unterschiedlicher tapioca-erganzung alleinfutter für milchkuhe. Wirtschaftseigne Futter, 19, 247–253.

Monod, J. 1942. Recherches sur la croissances des cultures bactériennes. Paris, France, Hermann et Cie.

Montaldo, A. 1973. Importancia de la yuca en el mundo actual con especial referencia a Venezuela. In Seminario nacional sobre yuca, Tacarigua, Venezuela. Rev. Fae. Agron. (Maracay), 22, 17–40.

Montaldo, A., and Montilla, J. J. 1976. Producción de follaje de yuca. Rev. Fac. Agron. (Maracay), 24, 35–51.

Montilla, J. 1977. Personal communication.

1971. La raiz de yuca en la alimentation animal. Rev. Protinal, 18, 120.

1976a. Utilization of the whole cassava plant in animal feeding. Paper presented at the first international symposium on feed composition, animal nutrient requirements, and computerization of diets. Logan, Utah, USA, 11–16 July 1976, 16p.

1976b. Utilization of the whole cassava plant in animal feed. Maracay, Universidad Central de Venezuela, Fac. Cienc. Vet. 17p.

Montilla, J. J., Castillo, P. P., and Wiedenhofer, H. 1975. Efecto de la incorporación de harina de yuca amarga en raciones para pollos de engorde. Agron. Trop. 25, 259–266.

Montilla, J. J., Garcia, I. A., and Reverón, A. E. 1973. Valor pigmentante de diversas harinas verdes agregadas a las raciones-para pollos de engorde y su efecto sobre el incremento de peso. Cienc. Vet. (Maracay), 2, 285.

Montilla, J. J., Méndez, C. R., and Wiedenhofer, H. 1969. Utilización de la harina de tubércuto de yuca (*Manihot esculenta*), en raciones iniciadoras para pollos de engorde. Arch. Latinoam. Nutr. 19(4), 381–388.

1970. Utilización de la harina de raíz de yuca (*Manihot esculenta*) en raciones para pollos de engorde. In Comun. Cient, XIV Congr. Mundial Avicult., Madrid, España, 985p.

Montilla, J. J., Vargas, R., and Montaldo, A. 1976. Efecto de varios niveles de harina de follaje de yuca en raciones para pollos de engorde. Rev. Fac. Agric. Univ. Cent. Venez. 24, 53.

Montilla, T., Vargas, R., and Montilla, J. J. 1970. Liberación de ácido cianhídrico de la raíz y el follaje de yuca. Acta Cienc. Venez. (Caracas), 27(1), 169–170.

Moore, C. P. 1976. The utilisation of cassava forage in ruminant feeding. International seminar in tropical livestock products, Acapulco, Mexico, March 8–12, 1976, 21p.

Morimoto, H. 1950. On the feeding values of pineapple bran and tapioca ampas for dairy cows. Jpn. J. Zootec. Sci. 21, 49–53.

Mota, T. P. 1970. Características quimico-analiticas de algumas mandiocas em ensaio. Agron. Moçabicana (Lourenço Marques), 4(1), 21–29.

Mudgal, V. D., and Sampath, S. R. 1972. Review of research work carried out in animal nutrition. In National Dairy Research Institute, Karnal, India. 68p.

Müller, Z. 1974. To improve the nutritive and economic value of the cassava root product. Comments and reports of the proposed IDRC/KKU project. (Unpublished paper.)

Müller, Z., Chou, K. C., Nah, K. C. 1974a. La yuca como sustituto total de cereales en las raciones del ganado y de las aves de corral. Rev. Mundial Zootecnia (FAO, Roma), 12, 19–24.

Müller, Z., Chou, K. C., and Nah, K. C. 1974b. Cassava as a total substitute for cereals in livestock and poultry rations. World Anim. Rev. 12(1), 19–24.

1975a. Cassava as a total substitute for cereals in livestock and poultry rations. Proceedings of the 1974 tropical products institute conference, 1–5 April, 85–95.

1975b. Cassava as a total substitute for cereals in livestock and poultry rations. UNDP/SF Project, 37–45.

Müller, Z., Chou, K. C., Nah, K. C., and Tan, T. K. 1972. Study of nutritive value of tapioca in economic rations for growing-finishing pigs in the tropics. In UNDP/SF project SIN 67/505, pig and poultry research and training institute, Singapore (pigs), vol. 672, 1–35.

Mushett, C. W., Kelley, K. L., Boxer, G. E., and Richards, J. C. 1952. Antidotal efficiency of vitamin B_{12} in experimental cyanide poisoning. Proc. Soc. Exp. Biol. 81, 234–236.

Nagarajan, V., Bhat, R. V., and Tulpule, P. G. 1973. Aflatoxin-like factor in tapioca (*Manihot utilissima*). Environ. Physiol. Biochem., 3(1), 13–18.

Nartey, F. 1963. Studies on cassava *Manihot utilissima* Pohl. I. Cyanogenesis: the biosynthesis of linamarin and lotaustralin in etiolated seedlings. Phytochemistry, 7, 1307–1312.

1973. Biosynthesis of cyanogenic glucosides in cassava (*Manihot* spp.). In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 73–87.

Natarajan, K. R., Rhee, K. C., Carter, C. M., and Mattil, K. F. 1973. Detoxification of aflatoxins in raw peanuts and peanut meal by sodium hypochlorite. Illinois, Abstract American

chemical society, 166th meeting, August, abstr. 79.

Nestel, B. L. 1974. Current trends in cassava research. In Nestel, B., ed., Ottawa, International Development Research Centre, IDRC-036e, 32p.

1975. World animal production and feed supplies. In Proceedings of the conference on animal feeds in tropics and subtropics held at the London School of Pharmacy, London, 1–5 April 1974. London, Tropical Products Institute, 15–21.

Neves, J. D. 1969. A substituição de farelo de algodão na alimentação de bovinos. Bol. Technico. 37, 3–18.

Neves, J. D. et al. 1969. Uréia, melaco e raspa de mandioca, na engorda de bovinos. Pernambuco, Brazil, Secretaría de Agricultura, Industria e Comercio, Instituto de Pesquisas Agronómicas de Pernambuco. Boletim Téc. 37, 18p.

Ng, B. S., and Hutagalung, R. I. 1974. Evaluation of agricultural products and by-products as animal feeds. III. Influence of dehydrated poultry excreta supplementation in cassava diets on growth rate and feed utilization of chickens. Malay. Agric. Res. 3, 242–253.

Nielsen, O. 1976. Isolation and preliminary characterization of aconidial, cold-sensitive and cyanide-resistant mutants of *Aspergillus fumigatus* I-21. M.Sc. thesis, University of Guelph, Guelph, Canada. 80p.

Nordström, U. M. 1974. Bark degradation by aspergillus fumigatus. Growth studies. Can. J. Microbiol. 20(3), 283–298.

Normanha, E. S. 1962. Farelo de ramas e folhas de mandioca. Agronomia, 14, 16–19.

NRA (National Renderers Association). 1974. The nutritive value of feed grade animal fat. National Renderers Association, Far East Office, Tokyo, Japan, 1–5.

NRC. 1973. Nutrient requirements of swine, 7th revised edition, National Research Council. In Washington, D.C., National Academy of Sciences, 1–56.

Oberleas, D., Muhrer, M. E., and O'Dell, B. L. 1966. Dietary metal-complexing agents and zinc availability in the rats. J. Nutr. 90, 56.

Obregon, R., and Juarez, G. 1955. Comparacion entra follaje de yuca y alfalfa. Estac. Exp. Lima, Peru.

Oh, S. Y. 1976. Cyanide detoxification in the domestic fowl. Unpublished Ph.D. thesis, Faculty of Agriculture, University of Malaya, Kuala Lumpur, 137p.

Oh, S. Y., and Jalaludin, S. 1972. The effect of feeding tapioca on growth rate of chicks. Malay. Agric. Res. 1, 144–146.

Oke, L. 1966. Chemical studies on some Nigerian foodstuffs "gari". Nature (Lond.), 212, 1055–1056.

Oke, O. L. 1968. Cassava as food in Nigeria. World Rev. Nutr. Diet, 9, 272.

1969. The role of hydrocyanic acid in nutrition. World Rev. Nutr. Diet. 11, 170–198.

1973a. The mode of cyanide detoxification. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 97–104.

1973b. Leaf protein research in Nigeria: A review. Trop. Sci. 15, 139–155.

Olaluku, E. A., Egbuiwe, A. M., and Oyenuga, V. A. 1971. The influence of cassava in the production ration on the yield and composition of White Fulani cattle. Nigerian Agric. J. 8, 36–43.

Oldfield, J. E., Schubert, J. R., and Muth, O. H. 1963. Implication of selenium in large animal nutrition. J. Agric. Food Chem. 11, 388–390.

Olson, D. W., Bird, H. R., and Sunde, M. L. 1968. Metabolizable energy and feeding value of mandioca meal. Poult. Sci. 47, 1703.

Olson, D. W., Sunde, M. L., and Bird, H. R. 1969a. Amino acid supplementation of mandioca meal in chick diets. Poult. Sci. 48, 1949–1953.

1969b. The metabolizable content and feeding value of mandioca meal in diets for chicks. Poult. Sci. 48, 1445–1452.

Omole, T. A., and Eshiett, E. 1976. Addition of methionine to cassava based rations for rabbits. In Progress report on "the use of cassava as animal feed in Nigeria." Submitted to IDRC in September, 22–23.

Osuntokun, B. O. 1972. Chronic cyanide neurotoxicity in Nigerians. Plant Foods Hum. Nutr. 2, 215–266.

1973. Ataxic neuropathy associated with high cassava diets in West Africa. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 127–138.

Oswaldo, P. C. 1966. La yuca (cassava). Agrotecnia, 2, 22p.

Oyenuga, V. A. 1955a. Nigerian feedstuffs. Ibadan, University College.

1955b. The composition and nutritive value of certain feedingstuffs in Nigeria. I. Roots, tubers and green leaves. Emp. J. Exp. Agric. 23(90), 81–95.

1961. Nutritive value of cereal and cassava diets for growing and fattening pigs in Nigeria. Br. J. Nutr. 15, 327–338.

1968. Nigeria's foods and feedingstuffs. Ibadan, Ibadan University Press.

Oyenuga, V. A., and Amazigo, E. O. 1957. A note on the hydrocyanic acid content of cassava (*Manihot utilissima* Pohl). West Afr. J. Biol. Chem. 1, 39–43.

Oyenuga, V. A., and Opeke, L. K. 1957. The value

of cassava rations for pork and bacon production. West Afr. J. Biol. Chem. 1, 3.

Palisse, M., and Barratou, J. 1974. Le manioc et les petates douces, matières premières glucidiques pour le poulet de chair. Paris, France, Conference on poultry and rabbit research, 165–167.

Patel, B. M., and Yamadagni, S. 1972. Comparative effects of feeding two leguminous by-products on various nitrogen fractions of rumen liquor and blood of cows. Indian J. Anim. Sci. 42, 180–184.

Paula, R. D. de G. 1952. Alimentos. Secc. II. Casa del Estudante de Brasil, Edit, Rio de Janeiro.

Paula, R. D. de G., and Cavalcanti. 1952. Bol. Inst. Nac. Tech. (Rio de J.), 3, 21.

Pearson, R. M., and Smith, J. A. B. 1943. The utilisation of urea in the bovine rumen. III. The synthesis and breakdown of protein in rumen digesta. Biochem. J. 37, 153–164.

Pechnik, E., and Guimaraes, L. R. 1962. Sôbre o aproveitamento da fôlha de mandioca, (*Manihot* sp.) na alimentaciao humana. III. Mandioca mansa. Arq. Bras. Nut. 18(1–2), 25–36.

1963. Sôbre o aproveitamento da fôlha de mandioca, (*Manihot* sp.) na alimentaçĩao humana. IV. Efeito da suplementacão de aminoacidos sintéticos sôbre o valor alimentico da fôlha de mandioca-mansa secada ao ar e em refrigerador Arq. Bras. Nutr. 19(2), 11–20.

Pechnik, E., Guimaraes, L. R., and Panek, A. 1962. Sôbre o aproveitamento da fôlha de mandioca, (*Manihot* sp.) na alimentaçĩao humana. II. Contribução ao estudo do valor alimenticio. Arq. Bras. Nutr. 18(1–2), 11–23.

Pederson, C. S. 1971. Microbiology of food fermentation. Westport, Conn., USA, Avi Publishing Co. Inc., 283p.

Peixoto, R., Grossman, J. R., and Oliveira, de W. M. 1955. A raíz da mandioca comparada com o grão de milho na produção de leite. Bol. Prod. Anim. 12, 24–27.

Pereira, A. S. 1966. Aipim (mandioca) para vaca leiteira. Charac Quintais, 113, 13–14.

Pernot, S. 1909. L'utilisation de la farine de manioca dans l'alimentation des jeunes veaux. Le Agriculture Pratique des Pays Chauds, 9, 427.

Perzow, B. 1974. Fermentation of whey. Ottawa, Presented at the whey utilization symposium.

Peyrot, F. 1969. Role nutritionnel de certaines feuilles alimentaires tropicales. Paris, France, University of the Faculty of Science, 61p.

Phillips, T. P. 1974. Cassava utilization and potential markets. Ottawa, International Development Research Centre, IDRC-020e, 1–182.

1974. World market prospects for cassava and its products. In Araullo, E. V. et al., ed., Cassava processing and storage: proceedings of an interdisciplinary workshop, Pattaya, Thailand, 17–19 April 1974. Ottawa, International Development Research Centre, 13–19.

Phuah, C. H. 1973/74. Effects of protein and mineral supplementation in cassava diet on performance and body composition of broiler chicks. B. Agricultural science project paper. Kuala Lumpur, University of Malaya, 176p.

Phuah, C. H., and Hutagalung, R. I. 1974. Effect of levels of dietary protein and cassava on performance and body composition of chickens. Malay. Agric. Res. 3, 99–106.

1977. The effects of zinc and iodine supplementation in the cassava diets on performance and body composition of broiler chicks. Malay. Agric. J. (in press).

Phuah, C. H., Hutagalung, R. I., Chong, S. K., and Kwan, F. S. 1974. Effects of flavouring agents and molasses on feed intake and growth performance of broiler chicks. 17p. (unpublished report).

Pillai, K. S. 1976. Relative susceptibility of cassava chips of different varieties to storage pest *Araeceras fasciculatus* DeGeer. Trivandrum, Central Tuber Crops Research Institute.

Pillai, S. C., Srimath, E. G., Mathin, M. L., Naidu, P. M. N., and Muthana, P. G. 1968. Tapioca spent pulp as an ingredient in poultry feed. Curr. Sci. 37, 603–605.

Pineda, M. J., and Rubio, R. R. 1972. Un concepto neuvo en el levante de novillas para ganaderia de leche. Rev. ICA, 17, 405–413.

Pirie, N. W. 1960. Abstract. Fifth international congress on nutrition, Washington.

Pond, W. G., and Maner, J. H. 1974. Swine production in temperate and tropical environments. San Francisco, Calif., USA, W. H. Freeman & Company.

Preston, T. R. 1974. Sugar cane as the basis for intensive animal production in the tropics. London, Proc. T.P.I. conf. on animal feeds of tropical and sub-tropical origin, 1–5 April 1974, 69–84.

Preston, T. R., and Willis, M. B. 1969. Sugarcane as an energy source for the production of meat. Outlook Agric. 6, 29–35.

Protein Advisory Group Statement No. 4. 1970. On single cell protein. PAG Bull., United Nations System, New York.

No. 6. 1970. For preclinical testing of novel sources of protein. PAG Bull., United Nations System, New York.

Protein–Calorie Advisory Group Guideline No. 15. 1974. On nutritional and safety aspects of novel protein sources for animal feeding. PAG Bull., United Nations System, New York.

Pyanaert, L. 1951. Le manioc, 2nd Edition. Bruxelles, Ministere des Colonies.

Ramirez, A., and Kowalczyk, J. 1971. Synthesis of microbial protein in bulls fed protein-free diet based on molasses urea. Rev. Cubana Cienc. Agric. 5, 21–26.

Ramos-Ledon, L., and Popenoe, J. 1970. Comparative chemical composition of cultivars of

Manihot esculenta Crantz and some related species. In Proceedings of the tropical region. American Society for Horticultural Science, vol. 14, 232–234.

Rao, N. D., Sreeramamurthy, V. V., and Venkateswarlu, P. 1951. The supplementary effect of pulses and rice on tapioca diet. Indian J. Med. Res. 39(3), 329–336.

Raymond, W. D., Jojo, N. Z., and Nicodemus, Z. 1941. The nutritive value of some Tanganyika foods. II. Cassava. East Afr. Agric. J. 6, 154–159

Razafimahery, R. 1953. Gluosides cyanogénetigues; pois du Cap, manioc et "Bononoka." Bull. Acad. Malgache, 31, 71–77.

Razdan, M. M., Sharma, D. D., Bharagava, P. K., and Chawla, M. C. 1971. Utilisation of urea and water metabolism by Zebu cattle and buffalo under tropical conditions. J. Dairy Sci. 54, 1200–1206.

Reade, A. E., and Gregory, K. F. 1975. High-temperature production of protein-enriched feed from cassava by fungi. Appl. Microbiol. 30(16), 897–904.

Reade, A. E., and Smith, R. H. 1975. Barley grain as carbon substrate for fungal protein production in a farm process. J. Appl. Chem. Biotechnol. 25, 785–799.

Reid, J. T. 1953. Urea as a protein replacement: A review. J. Dairy Sci. 36, 955.

Rendón, M., Benítez, H., and Marin, O. 1969. Utilización de la yuca (*Manihot esculenta*) en el engorde de pollos asaderos. Rev. ICA, 4(3), 159–171.

Rhodes, A., and Fletcher, D. L. 1966. Principles of industrial microbiology. Oxford, England, Pergamon Press Ltd.

Rhodesia, Southern Govt. Poultry Station. 1943. Report on experimental feed trials. Rhod. Agric. J. 40, 125–127.

Robertson, R. H., and Trujillo. 1975. The effect of methionine, thiouracil, diestol, diacetate and thyroprotein on the development and prevention of fatty liver in pullets. Poult. Sci. 54, 715–721.

Rogers, C. J., Coleman, E., Spino, D. F., and Purcell, T. C. 1972. Production of fungal protein from cellulose and waste cellulosics. Environ. Sci. Technol. 6(8), 715–719.

Rogers, D. J. 1959. Cassava leaf protein. Econ. Bot. 15, 302.

1963. Studies of *Manihot esculenta* Crantz and related species. Bull. Torrey Bot. Club, 90, 43.

Rogers, D. J., and Milner, M. 1963. Amino-acid profile of manioc leaf protein in relation to nutritive value. Econ. Bot. 17, 211–216.

Rogler, J. C., Parker, H. E., Andrew, F. N., and Carrick, C. W. 1961a. The iodine requirement of breeding hen. 1. Hens reared on a diet adequate in iodine. Poult. Sci. 40, 1546–1554.

1961b. The iodine requirement of breeding hen. 2. Hens reared on a diet deficient in iodine. Poult. Sci. 40, 1554–1562.

Rojas, I. 1968. Vitamina C en yucas peruanas y su variaction por coccion. Lima, Peru, Univ. Nac. Sn. Marcos, 56p.

Romantschuk, H. 1975. The Pekilo process: protein from spent sulfite liquor. In Tannenbaum, S. R., and Wang, D. I. C., ed., Single-cell protein II. Cambridge, Mass., USA, The M.I.T. Press, 344–356.

Ross, E., and Enriquez, F. Q. 1969. The nutritive value of cassava leaf meal. Poult. Sci. 48(3), 846–853.

Roverso, E. A., Tundisi, A. G. A., and Lima, F. P. 1969. Melaco, mandioca e cana-de-acucar integral no arracoamento de bovinos Nelore. Rev. Medica Vet. 5, 36–40.

Santos, N. J., and Gómez, G. G. 1977. Pilot plant for single-cell protein production. In Nestel, B., and Graham, M., ed., Cassava as animal feed: proceedings of a workshop held at the University of Guelph, 18–20 April 1977. Ottawa, International Development Research Centre, IDRC-095e, 91–94.

Savage, J. E., Yoke, J. M., Pickett, E. E., and O'Dell, B. L. 1964. Zinc metabolism in the growing chick. Tissue concentration and effect of phytate on absorption. Poult. Sci. 43, 420.

Schmidt, H. L. 1966. Die Mikroflora der Maniokafuttermittel. Getreide Mehl, 16(10), 105–110.

Scholz, H. K. B. W. 1972. Possibilidades de aproveitamento de partes aéreas da mandioca como forrageira. Fortaleza, Banco del Nordeste do Brasil. (Pesquisas tecnologicas sobre a Mandioca), 181–195.

Schubert, J., and Brill, W. A. 1968. Antagonism of experimental cyanide toxicity in relation to the *in vivo* activity of cytochrome oxidase. J. Pharmacol. Exp. Ther. 162, 352–359.

Scott, M. L., Nesheim, M. C., and Young, R. J. 1969. Nutrition of the chicken. Ithaca, N.Y., USA, M. L. Scott & Associates, 511p.

Sebastia, J. M., Martens, E. S., Oliveira, W. M., and Collares, A. 1973. Farina de mandioçã como substituto parcial do milho ha alimentação do frangos de corte. Pesqui. Agropecu. Bras. Ser. Zootéc. 8, 61.

Seeres, H. 1969. L'engraissement des zebus dans la région de Tananarive selon la technique du "boeuf de fosse". Rev. Elev. Med. Vet. Pays. Trop. 22, 429–439.

Seerly, R. W. 1972. Utilization of cassava as a livestock feed. A review. In Hendershott, C. H. et al., ed., A literature review and research recommendations on cassava. AID contract no. csd/2497. Athens, Georgia, USA, University of Georgia, 157–181.

Selye, H. 1950. The physiology and pathology of

exposure to stress. Montreal, Canada, Acta Inc., Medical Publishers.

Serck-Hanssen, A. 1970. Aflatoxin-induced fatal hepatitis. A case report from Uganda. Arch. Environ. Health, 20, 729–731.

Serres, H., and Tillon, J. P. 1972. L'ensilage des racines de manioc. Rev. Elev. Med. Vet. Pays Trop. 25(3), 455–456.

Shacklady, C. A., and Gatumel, E. 1972. The nutritional value of yeasts grown on alkanes. In Gounelle de Pontanel, H., ed., Protein from hydrocarbons. New York, USA, Academic Press Inc., 27–45.

Shank, R. C., Wogan, G. N., Gibson, J. B., and Nondasutu, A. 1972. Dietary aflatoxins and human liver cancer. II. Aflatoxins in market food and foodstuffs in Thailand and Hongkong. Food Cosmet. Toxicol. 10, 61–69.

Shenderei, E. R. 1976. Development of technology and experience in the use of single cell protein in animal feeding in the USSR. In PAG bulletin VI, No. 3. New York, Protein-calorie advisory group of the United Nations system, 18–24.

Shimada, A. S., Peraza, C., and Cabello, F. T. 1971. Valor alimenticio de la harina de yuca, *Manihot utilissima* Pohl, para cerdos. Tec. Pecu. Mex. 15–16, 31–35.

Schultz, E., Schultz, T. A., and Chicco, C. F. 1970a. Efecto del tratamiento por calor y presión sobre la utilización de la urea en rumiantes. Agron. Trop. (Maracay), 20(6), 421–432.

Schultz, T. A., Chicco, C. F., Shultz, E., and Carnevali, A. A. 1970b. Evaluación de diferentes fuentes de energía, yuca, maíz, arroz y melaza, sôbre la utilización de altos niveles de urea en bovinos. Agron. Trop. (Maracay), 20(3), 185–194.

Sidransky, H. 1975. Experimental studies with aspergillosis. In Chick, E. W., Balows, A., and Furcolow, M. L., ed., Opportunistic fungal infections. Springfield, Ill., USA, Charles C. Thomas Publisher, 165–176.

Sihombing, D. T. H., Cromwell, G. L., and Hays, V. W. 1971. Effect of added thiocyanate and iodine to corn-soybean meal diets on performance and thyroid status of pigs. J. Anim. Sci. 33, 1154.

1974. Effects of protein source, goitrogens and iodine level on performance and thyroid status of pigs. J. Anim. Sci. 39, 1116–1120.

Silva, J. R. da. 1966. Farelo de ramas e fôlhas de mandioca na alimentação animal. Chacaras Quintaes, 114(6), 663–666.

Singh, N. 1964. Leaf protein extraction from some plants of northern India. J. Food Sci. Technol. 1(3), 37–39.

Sinha, S. K., and Nair, T. V. R. 1968. Studies on the variability of cyanogenic glucoside content in cassava tubers. Indian J. Agric. Sci. 38, 958–963.

Sinha, S. K., et al. 1970. Note on the possibility of controlling increased cyanoglucoside content in cassava tuber caused by higher application of nitrogen. Indian J. Agric. Sci. 40(6), 573–575.

Siriwardene, J. A. de S., and Ranaweera, K. N. P. 1974. Manioc leaf meal in poultry diets. Ceylon Vet. J. 22(3), 52–57.

Skinner, C. E., and Muller, A. E. 1940. Cystine and methionine deficiency in mold proteins. J. Nutr. 19, 333.

Smith, A. D. M., and Puckett, S. 1965. Cyanide, vitamin B_{12}, experimental demyelination and tobacco amblyopia. Br. J. Exp. Pathol. 46, 615–622.

Smith, A. D. M., Puckett, S., and Waters, A. H. 1963. Neuropathological changes in chronic cyanide intoxication. Nature (Lond.), 200, 179–181.

Smith, A. M. 1961. Retrobulbular neuritism addisonian pernicious anaemia. Lancet i, 1001–1002.

Smith, R. H., and Palmer, R. 1976. A chemical and nutritional evaluation of yeasts and bacteria as dietary protein sources for rats and pigs. J. Sci. Food Agric. 27, 763.

Smith, R. H., Palmer, R., and Reade, A. E. 1975. A chemical and biological assessment of *Aspergillus oryzae* and other filamentous fungi as protein sources for simple stomached animals. J. Sci. Food Agric. 26, 785–795.

Snyder, H. E. 1970. Microbial sources of protein. Adv. Food Res. 18, 85.

Soares, P. R., Campos, J., and Conrad, J. H. 1968. Farelo integral de raspa de mandioçã e farelinho de trigo na alimentação de pintos. Experientiae, 8, 19.

Soewardi, B., Sastradipradja, D., Nasution, A. H., and Hutasoit, J. H. 1975. The influence of corn and cassava meal supplementation on the feeding value of alangalang (*Imperata cylidrica* (L) Beauv) Malay. Agric. Res. 4, 123–130.

Solomons, G. L. 1969. Materials and methods in fermentation. London, England and New York, USA, Academic Press Inc.

Sonaiya, E. D., Omole, T. A., and Adegbola, A. A. 1976. Effects of methionine-supplemented cassava meal diets on live performance and post mortem measurements of growing-finishing pigs. Nigerian J. Sci. (in press).

Sorbo, B. 1975. Thiosulfate sulfurtransferase and mercaptopyruvate sulfur transferase. In Greenberg, D. M., ed., Metabolic pathways. 3rd Edition, Vol. VII. New York, USA, Academic Press Inc., 433–453.

Spicer, A. 1973. Proteins from carbohydrates. Chem. Br. 9, 100.

Splittstoesser, W. E., and Rhodes, A. M. 1973. Protein and amino-acids values of some tropical root crops. Ill. Res. 15(4), 6–7.

Sprung, D. W. 1974. Improvement of the nutritional value of cassava by the use of high-solids fermentations. M.Sc. thesis, University of Guelph, Guelph, Canada, 91p.

Sreeramamurthy, V. V. 1945. Investigations on the nutritive value of tapioca. Indian J. Med. Res. 33, 229–238.

Standish, J. F., Ammerman, C. B., Simpson, C. F., Neal, F. C., and Palmer, A. Z. 1969. Influence of graded levels of dietary iron, as ferrous sulphate, on performance and tissue mineral composition of steers. J. Anim. Sci. 101, 445–452.

Stanton, W. R., and Wallbridge, A. 1969. Fermented food processes. Process Biochem. 4, 45–51.

1972. Improvements relating to the fermentation of cassava and other vegetable substances. British patent 1,277,002, 4p.

Starcher, B. C. 1969. Studies on the mechanism of copper absorption in the chick. J. Nutr. 97, 321–326.

Stecker, P. G. (editor). 1968. The Merck Index. Rahway, N.J., USA, Merck and Co. Inc., 544p.

Steel, R. G., and Torrie, J. H. 1960. Principles and procedures of statistics. Toronto, Canada, McGraw-Hill Book Co., Inc.

Strasser, J., Abbott, J. A., and Battey, R. F. 1970. Process enriches cassava with protein. In Food engineering, May 1970, 112–116.

Sullivan, T. W., and Kingan, J. R. 1962. Effect of dietary calcium level, calcium lactate and ascorbic acid on the egg production of White Leghorn hen. Poult. Sci. 41, 1596–1602.

Sutton, J. D., Smith, R. N., and Corse, D. A. 1970. Energy digestion and microbial synthesis in the rumen of sheep given hay and concentrates. In 5th Symposium on Energy Metabolism, 121p.

Syed Ali, A. B., Yeong, S. W., and Seet, C. P. 1975. Performance of layers fed high levels of broken rice and tapioca as a direct substitution for maize. MARDI Res. Bull. 3, 63–70.

Tabayoyong, T. T. 1935. The value of cassava refuse meal in the rations for growing chicks. Philipp. Agric. 24, 509.

Tasker, P. K. 1962. Supplementary value of groundnut flour and blends of groundnut flour and skim milk powder to a maize-tapioca diet. Food Sci. 11(6), 181–186.

Tejada de H., L., and Brambila, S. 1969. Investigaciones acerca del valor nutritivo de la yuca para el pollito. Tec. Pecu. Méx. 3, 329.

Temperton, H., and Dudley, F. J. 1941. Tropical meal as a feed for laying hens. Harper Adams Utility Poult. J. 26, 55–56.

Terra, G. J. A. 1964. The significance of leaf vegetables, specially of cassava in tropical nutrition. Trop. Geog. Med. 16, 97–108.

Tewe, O. O. 1975. Implications of the cyanogenic glucoside fraction of cassava in the growth and reproductive performance of rats and pigs. Ph.D. thesis, University of Ibadan, Nigeria.

Thanh, N. C., Pescod, M. B., and Muttamara, S. 1976. Technological improvement of tapioca chips and pellets produced in Thailand. IDRC final research report no. 57. Env. Eng. Div. AIT, Bangkok, Thailand, February 1976.

Thornton, P. A., and Moreng, R. E. 1959. Further evidence on the value of ascorbic acid for maintenance and shell quality in warm environmental temperature. Poult. Sci. 38, 594–599.

Tillon, J. P., and Serres, H. 1973. Le manioc dans l'alimentation du porc. II. Digestibilité du manioc sous differentes presentations. Rev. Elev. Med. Vet. Pays Trop. 26, 229–233.

Tsao, S. T. N. 1968. Vortex behavior in waldhof fermenter. Biotechnol. Bioeng. 10, 77–88.

Tucker, R. E., Little, C. O., Mitchell, G. E., Jr., Haya, B. W., and Karr, M. R. 1966. Starch digestion in different segments of the digestive tract of sheep. J. Anim. Sci. 25, 911 (abstr.).

Tutarov, G. A., Kyrova, U. E., and Tutaruva, E. D. 1967. Utilization of maize silage prepared with thiourea and diammonium phosphate. Kukuruza 11, 29 (cited in Herbage abstr. 40, 155, 1970).

Valdivieso, C. A., and Alba, J. de. 1958. Uso del maiz y la harina de yuca en mezclas simples para criar terneras de lecheria. Turrialba, 8, 148–152.

Valor Das Folhas. 1968. E ramas da mandioca. Agrominas (Brasil), 1(4), 16.

Van Campen, D. R. 1966. Effect of zinc, cadmium, silver and mercury on the absorption and distribution of copper-64 in rats. J. Nutr. 88, 125.

Van Der Velden, M., Kinthaert, J., Orts, S., and Ermans, A. M. 1973. A preliminary study on the action of cassava on thyroid iodine metabolism in rats. Br. J. Nutr. 30, 511.

Vander Wal, P. 1976. Experience with SCP in animal feeding in Europe. In PAG bulletin VI, no. 3. New York, Protein-calorie advisory group of the United Nations system, 7–18.

Van Veen, A. G. 1938. Over cassave-bladerem, een hoogwaardige bladgroente. Geneeskd. Tijdschr. Ned.-Indie, 78, 2548–2552.

van Weerden, E. J., Schulte, J. B., and Sprietsma, J. E. 1976. Relation between methionine and inorganic sulphate in boiler rations. Poult. Sci. 55(4), 1476–1481.

Varghese, G., Thambirajah, J. J., and Wong, F. M. 1977. Protein enrichment of cassava by fermentation with microfungi and the role of natural nitrogenous supplements. In Cock, J., MacIntyre, R., and Graham, M., ed., Proceedings of the fourth international symposium of the international society for tropical root crops held at CIAT, Cali, Colombia, 1–7 August 1976. Ottawa, International Development Research Centre, IDRC-080e, 250–255.

Velloso, L., et al. 1967. Estudo do valor de alguns fenos de plantas tropicais. Bol. Indus. Anim. (Brasil), 24, 53–57.

Velloso, L., Rodrigues, A. J., Becker, M., Neto, L. P., Scott, W. N., Kalil, E. B., Molotti, L., and

Da Roche, G. L. 1967. Substituição parcial e total do milho pelo farelo de mandioca em raçoes de suinos em crescimento e engorda. Bol. Ind. Anim. 23, 129–137.

Vogt, H. 1966. The use of tapioca meal in poultry rations. World's Poult. Sci. J. 22, 113–125.

Vogt, H., and Penner, W. 1963. Der Einsatz von Tapioca — und Maniokamehl im Geflügelmastfutter. Arch. Geflügelkd. 27, 431.

Vogt, H., and Stute, K. 1964. Prugung von Tapiocapellets im Geflügelmast-Alleinfutter. Arch. Geflügelkd. 28, 342.

Volesky, B., Zajic, J. F., and Carroll, K. K. 1975. Feeding studies in rats with high protein fungus grown on natural gas. J. Nutr. 105, 311.

Von Hofsten, B. 1976. Cultivation of a thermotolerant basidiomycete on various carbohydrates. In Brich, G. G., Parker, K. J., and Worgan, J. T., ed., Food from waste. London, England, Applied Science Publishers Ltd., 156–165.

Von Hofsten, B., and Ryden, A. 1975. Submerged cultivation of a thermotolerant basidiomycete on cereal flours and other substrates. Biotechnol. Bioeng. 17, 1183–1197.

Vosloh, C. J., Jr., Edwards, R. H., Enochian, R. V., Kuzmicky, D. D., and Kohler, G. O. 1976. Leaf protein concentrate (PRO-XAN) from alfalfa: an economic evaluation. Natl. Econ. Anal. Div. Econ. Res. Serv. Agri. Econ. Rep. No. 346, 38.

Vries, C. A. de, Ferwerda, J. D., and Flack, M. 1970. Choice of food crops in relation to actual and potential production in the tropics. Neth. J. Agric. Sci. 15, 241.

Waldron, C., and Roberts, C. F. 1974. Cold-sensitive mutants in *Aspergillus nidulans*. II. Mutations affecting ribosome production. Mol. Gen. Genet. 134, 115–132.

Walker, A. 1951. Un aliment de famine: l'écorce de Manioca. Rev. Int. Bot. Appl. 31, 542.

Walker, D. J. 1970. Cited by Hogan, J. P., and Weston, R. H. 1970. Quantitative aspects of microbial protein synthesis. Proceedings of the third international symposium on physiology of digestion and metabolism in the ruminant, 474p.

Wassermann, A. E., and Hampson, J. 1961. Whey utilization, growth of kluyveromyces fragilis in whey in a pilot plant. J. Dairy Sci. KL IV (3), 307–392.

Wegner, R. M. 1961. Zur verbilligung von kukenmast-futer mischungen. Kraftfutter, 44, 84.

Weinshank, D. J., and Carver, J. C. 1967. Theory and design of aerobic fermentations. In Microbial technology. New York, USA, and London, England, Reinhold Publishing Corp.

Wexler, J., Whittenberger, J. L., and Dumke, P. R. 1947. The effect of cyanide on the electrocardiogram of man. Am. Heart J. 34, 163–173.

Wheeler, J. L., Hedges, D. A., and Till, A. R. 1975. A possible effect of cyanogenic glucoside in sorghum on animal requirements for sulphur. J. Agric. Sci. 84, 377–379.

Wilson, J. 1973. Cyanide and human disease. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. Ottawa, International Development Research Centre, IDRC-010e, 121–125.

Wilson, H. R., Fry, J. C., Harms, R. H., and Arrington, L. R. 1967. Performance of hens molted by various methods. Poult. Sci. 46, 1406–1412.

Wilson, H. R., and Harms, R. H. 1972. High levels of dietary iodine and sexual maturity in males. Poult. Sci. 51, 742–746.

Wilson, H. R., and Rowland, L. O., Jr. 1970. Reproductive characteristics in cockerels fed a high level of iodine. Poult. Sci. 49, 804–808.

Winkler, W. O. 1958. Report on methods for glucosidal HCN in lima beans. J. Assoc. Off. Agric. Chem. 41, 282–287.

Wokes, F., Badenoch, J., and Sinclair, H. M. 1955. Human dietary deficiency of vitamin B_{12}. Am. J. Clin. Nutr. 3, 375–382.

Wokes, F., and Picard, C. 1955. Detoxication of cyanide by cystine. J. Biol. Chem. 218, 449.

Wokes, F., and Pickard, C. W. 1955. The role of vitamin B_{12} in human nutrition. Am. J. Clin. Nutr. 3, 383–390.

Wollman, H., and Dripps, R. D. 1970. In Goodman, L. S., and Gilman, A., ed., The pharmacological basis of medicine, 4th ed. Toronto, Canada, Macmillan Company of Canada Ltd.

Wood, T. 1965. The toxic and nutritional qualities of cassava. West Afr. Pharm. 7, 2.

Wood, T. J. 1965. The cyanogenic glucoside content of cassava and cassava products. J. Sci. Food Agric. 16, 300.

Wood, J. L., and Cooley, S. L. 1956. Detoxification of cyanide by cystine. J. Biol. Chem. 218, 449–457.

Worker, N. A. 1957. A note on the detoxification of cyanide in ruminants. N.Z. J. Sci. Technol. 38, 709.

Wu, L. W. T., and Flores, M. 1961. Tablas de composicion de alimentes. Guatemala, Inst. Nutr. C. America y Panama.

Yeong, S. W., and Syed Ali, A. B. 1976a. The use of tapioca in broiler diets. MARDI Res. Bull. (in press).

1976b. The use of tapioca in layer diets. MARDI Res. Bull. 4, 91–96.

Yoshida, M. 1970. Bioassay procedure of energy source for poultry feed and estimation of available energy of cassava meal. J. Agric. Res. Quart. 5, 44–47.

Yoshida, M., Hoshu, H., Kosaka, K., and Morimoto, H. 1966. Nutritive value of various energy sources for poultry feed. IV. Estimations

of available energy of cassava meal. Jpn. Poult. Sci. 3, 29–34.

Zausch, M., Drauschke, M., and Lauterbach, A. 1968. Digestibility and use of cassava meal by pigs. J. Tierernähr. Futterung, 6, 256.

Zitnak, A. 1973. Assay methods for hydrocyanic acid in plant tissues and their application in studies of cyanogenic glycosides in *Manihot esculenta*. In Nestel, B., and MacIntyre, R., ed., Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England, 29–30 January 1973. International Development Research Centre, IDRC-010e, 89–96.

Zitnak, A., Hill, D. C., and Alexander, J. C. 1977. Determination of linamarin in biological tissues. Anal. Biochem. 77, 310–314.

Zoby, J. L. F., Campos, J., Mayrose, V., Melgact, P., and Costa, A. 1971. Raspa de mandioca com supplementação de gordura e metionina, na alimentação de suinos. Rev. Ceres, 18, 195.