METHODOLOGY TO EVALUATE THE NUTRITIVE VALUE OF FEEDSTUFFS FOR POULTRY AND SWINE

by

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INTRODUCTION

The nutritional surveys conducted in most tropical countries have amply demonstrated the problem of inadequate animal proteins in the diets of an average citizen. One of the quickest ways of improving the situation is by increasing the production of non-ruminant animals, such as swine and poultry. However, the greatest single item that has limited the expansion of swine and poultry industries of these countries is the scarcity and high cost of traditional feed ingredients. Although vast potential exists for increasing the supply of cheaper, non-traditional feed resources, there is a paucity of published information on the nutrient composition and the limitations of their use in animal feeding. This lack of information has hindered efforts by nutritionists to utilize them effectively in feed formulation. Precise knowledge on the nutrient composition of feedstuffs is critical for the formulation of diets that will be effectively utilized. The ever increasing awareness of specific requirements for nutrients further highlights the urgent need to characterize the nutrient contents of tropical feedstuffs.

Knowledge of the available energy content of feedstuffs is another essential factor if the most economical diets are to be formulated. In the past, the poultry feed industry has relied on metabolizable energy corrected to nitrogen equilibrium (ME_n) as the estimate of available energy in feedstuffs. These values, however, have been reported to vary widely depending on many factors including methodology, strain of birds, age, sex and level of feed intake (Sibbald, 1980a). Furthermore,

according to Sibbald (1976a), the ME_n do not correct for the metabolic fecal and endogenous urinary energy losses. A rapid true metabolizable energy (TME) bioassay which overcomes the above drawbacks has been described by Sibbald (1976a). This method involves force-feeding of starved adult roosters with the test ingredient and then correcting excreta voided during the next 24 hours for energy losses of metabolic and endogenous origin, which are determined with a "paired" starved rooster.

Since the development of TME bioassay is relatively recent, published information on the TME values of tropical feedstuffs is non-existent.

The ability of swine to digest and utilize fiber has been known for almost a century. The energy from fibrous ingredients is apparently made available to swine by fermentation in the lower intestinal tract. While low levels of fiber may act as a growth stimulant, high levels have been repeatedly demonstrated to have an inhibitory effect on the growth of swine. Although this growth inhibitory effect has been attributed to possible interference with the absorption of essential nutrients, it still remains an area of uncertainty. In view of the scarcity and high cost of traditional feeds, fibrous feedstuffs may be expected to be increasingly used in swine feeding in the future. Therefore, it is imperative to clearly understand the relationship between fiber level and digestibilities of other nutrients.

Fiber heas been shown to increase the passage rate of ingesta in the digestive tract (Kass et al., 1980a), and this may be a possible mode of action by which high dietary fiber depresses the nutrient digestibil-

ities. In contrast Virginiamycin, an antibiotic developed for use in animal feeding, appears to have a slowing effect on the passage rate of ingesta. Hence, its possible interaction of fibrous feeds by swine.

The overall objective of this investigation was to evaluate some of the methodology used to determine the nutritive value of feedstuffs for poultry and swine. However, the more specific objectives were as follows:

1) characterization of the nutrient composition of six tropical feedstuffs,
2) determination of the true metabolizable energy values of three tropical feedstuffs for poultry,
3) determination of the effects of Virginiamycin and dietary fiber on the passage rate of ingesta and nutritional parameters of growing swine, and
4) comparison of the conventional total collection method and the indicator method for determining nutrient digestibilities in swine.

Chapter II

REVIEW OF LITERATURE

CASSAVA TUBER MEAL

The high cost and shortage of corn during the recent years have highlighted the urgent need for a search for alternative sources of energy to support the swine and poultry industries of many tropical areas. One feed source which could play an important role in this context is cassava (*Manihot esculenta Crantz*). Of all the tropical crops, cassava is capable of providing the highest yield of energy per hectare, this being about 13 times more than corn (Oyenuga, 1961). Fresh tuber yields usually vary from 3-20 tons/ha under tropical conditions, but with reasonable soil fertility and improved management practices 45 tons/ha are not uncommon. Varieties have also been identified that produce 75 to 80 tons/ha per year (Varon, 1968). The ability of cassava to grow in sub-optimal soil and environmental conditions offers it a competitive superiority over corn. Perhaps this is the most significant aspect to be considered in evaluating the role of cassava in tropical animal feed production systems.

CARBOHYDRATES

Cassava tuber meal (CTM) is primarily a source of energy with a nitrogen-free extract content of about 90% (Oke, 1978), which consists of 80% starch and 20% sugar (Vogt, 1966). The high starch content makes cassava highly digestible for non-ruminant animals. Amylose and amylopectin together constitute 99% or more of the cassava starch (Johnson

and Raymond, 1965). The most important sugar is sucrose, which accounts for as much as 17% of the dry matter in some sweet cultivars. Small quantities of fructose and dextrose are also reported, but these may have been formed by the action of the enzymes on sucrose (Seerly et al., 1972). Maghuin-Rogister (1968) isolated and identified a new disaccharide, manicose, in cassava flour. Wide variations, ranging from 1.7% (Vogt, 1966) to 6.1% (Gerpacio, 1979), have been reported in the crude fiber content of CTM (Table 1). While varietal differences may explain part of it (Maner, 1973), inclusion of peels in the preparation of meal appears to be the major factor causing this variation.

PROTEIN AND AMINO ACID PROFILE

One of the major problems in utilizing CTM in animal feeding is its low protein content when compared to corn (Table 1). The total nitrogen of CTM consists of 60% amino acid nitrogen and 1% nitrates, nitrites and hydrocyanic acid, with the remainder unidentified (Anon, 1973). The amino acid composition of CTM, when expressed on a total basis, compares unfavorably with that of corn (Table 2). Sulfur amino acids are essentially trace elements in CTM. Supplementation of these amino acids is therefore necessary when cassava-based rations are fed to non-ruminants.

LIPIDS

CTM contains low levels of lipids and, therefore, is likely to be deficient in essential fatty acids. CTM has only around 0.5% ether extractable material (Table 1), while most animals require 1-2% lipids in their diets. Hudson and Ogunsu (1974) reported that lipids of CTM

contain only 14.6% linoleic acid compared to 60.8% for corn lipids.

Addition of fat and oil to cassava-based rations has been reported to improve growth rate and feed efficiency in poultry (Ng and Hutagalung, 1974) and swine (Hew, 1972). However, the deficiency should not be a concern in practical cassava-based rations as increased amounts of oil meals are usually added to make up for the lower protein. The response to fat supplementation may have been due to other reasons, such as improved palatability, reduced dustiness and better absorption or retention of other nutrients especially at high levels of CTM.

MINERALS AND VITAMINS

Cassava tuber meal is a poor source of minerals (Wyllie and Lekule, 1980). Fetuga and Oluyemi (1976) reported a calcium content of 0.58% in their CTM samples. The excessive calcium reported in their study may have been due to contamination with soil (Khajarern et al.,1979). In addition, cassava tuber normally contains around 3.20% oxalic acid (Oke, 1970), which may upset the normal relationships of dietary Ca, P and Zn. Maust et al. (1972a) observed parakeratosis in swine fed high cassava diets containing normal levels of Zn. This condition was eliminated by the addition of zinc carbonate.

CTM contains nutritionally significant amounts of thiamine, riboflavin and niacin (Seerly et al., 1972). CTM is also rich in ascorbic acid (Jones, 1959), but it may be entirely destroyed during processing.

TABLE 1. PROXIMATE COMPOSITION OF CORN AND CASSAVA TUBER MEAL (PERCENT OF DRY MATTER)

	Corn[a]	Cassava					
		1[a]	2[b]	3[c]	4[d]	5[e]	6[f]
Crude protein	8.8	2.5	2.1	3.6	2.2	2.8	2.0
Ether extract	3.7	1.0	0.5	0.4	0.5	0.3	0.4
Crude fiber	2.5	6.1	1.7	3.0	2.2	4.0	2.4
Ash	1.9	3.1	1.5	1.0	2.7	2.0	1.9
Nitrogen-free extract	83.1	87.3	94.2	92.0	92.4	90.8	93.3

[a]Gerpacio, 1979 (Philippines)
[b]Vogt, 1966 (Congo)
[c]Olson et al., 1969b (Brazil)
[d]Fetuga and Oluyemi, 1976 (Nigeria)
[e]Khajarern et al., 1979 (Thailand)
[f]Wyllie and Lekule, 1980 (Tanzania)

TABLE 2. AMINO ACID COMPOSITION OF CORN AND CASSAVA TUBER MEAL (PERCENT OF DRY MATTER)

Amino Acid	Corn[a]	Cassava 1[b]	Cassava 2[c]
Aspartic acid	0.78	0.17	0.07
Threonine	0.45	0.06	0.06
Serine	0.63	0.06	-
Glutamic acid	2.51	0.42	0.36
Proline	-	0.08	0.07
Glycine	0.43	0.07	0.05
Alanine	0.95	0.15	0.11
Valine	0.52	0.08	0.06
Cysteine	0.17	-	0.04
Methionine	0.07	0.02	0.02
Isoleucine	0.38	0.06	0.05
Leucine	1.64	0.10	0.07
Tyrosine	0.46	0.06	0.04
Phenylalanine	0.62	0.07	0.05
Lysine	0.31	0.16	0.08
Histidine	0.37	0.06	0.03
Arginine	0.57	0.33	0.21
Total	10.86	1.95	1.37

[a]Owusu-Domfeh *et al.*, 1970 (Ghana)

[b]Orok and Bowland, 1974b (Nigeria)

[c]Wyllie and Lekule, 1980 (Tanzania)

CYANOGENIC GLUCOSIDES

A major factor which has limited the widespread use of cassava is its cyanogenic glucosides, namely linamarin and lotaustralin. The former accounts for 93% of the total glucosides and the latter 7% (Nartey, 1968). Upon hydrolysis, these glucosides yield hydrocyanic acid, which is a powerful respiratory poison. In animals, while acute cases of cyanide toxicity usually result in sudden death, less severe cases may lead to gastrointestinal troubles and growth depression (Hill, 1973). Acute poisoning as a result of consuming cassava by man or domestic animals is not common, but by no means unknown. Hill (1973) reviewed the available literature and concluded that cyanide toxicity appears not to be a serious practical problem in the utilization of cassava by domestic animals.

With reference to animal feeding, interest has centered on utilizing varieties inherently low in the glucosides and in processing methods that reduce the toxicity. It is well known that considerable variation exists in the cyanogen content of different varieties. The normal range of cyanogen content is from 75 to 350 ppm (Oke, 1978), but occasional samples containing as low as 10 ppm or over 2000 ppm have been reported (Rogers, 1963).

Various processing methods can be employed to reduce the cyanide toxicity of cassava tubers. Soaking or boiling in water, sundrying, ovendrying at moderate temperatures (60° C), roasting and fermentation are some of the methods commonly used (Coursey, 1973). Since the cyanide content is substantially higher in the peel fraction of the tuber than in the flesh, the ratio being over 10:1 (Rajaguru, 1975), removal

of peel appears to be the simplest way of reducing cyanide toxicity. Rajaguru (1972/73) reported that a combination of drying and soaking in water is effective in reducing the toxicity even in unpeeled cassava tubers.

The animal body detoxifies cyanide via several pathways, but principally by reaction with thiosulfate to form thiocyanate (Montgomery, 1969). Cystine and methionine act as sulfur donors in these reactions. Thiocyanate, the detoxification product, is a potent goitrogen and has been implicated in the etiology of goiter in humans (Ekpechi et al., 1966). No such effects, however, have been reported in domestic animals.

CASSAVA FOR SWINE

The interest in the use of cassava in modern swine nutrition probably originated with the studies of Oyenuga and Opeke (1957) who substituted cassava meal for sorghum at 40 and 50% levels in rations for growing and finishing swine, and concluded that the feeding value of cassava is comparable to that of sorghum. Oyenuga (1961) evaluated boiled and raw cassava as replacements for sorghum and reported that for growing swine cassava could satisfactorily replace sorghum at levels not exceeding 42% and that boiling cassava would not lead to improved performance. When the level of cassava was increased to 55%, boiling improved performance which was attributed to better retention of N, Ca and P.

Aumaitre (1969) compared rations containing 50% cassava meal with those containing corn, wheat, barley and oats at the same level, and observed the performance of weanling swine fed cassava to be clearly

superior to those fed the different cereals. The superiority of cassava was attributed to improved dry matter and energy digestibilities and to decreased incidence of diarrhea. He determined a digestible energy value of 4.19 kcal/g for cassava, while the values for the cereals were around 4 kcal/g. Several workers have reported better digestiblity of cassava-based rations for swine than of cereal-based rations (Henry, 1971; Chicco et al., 1972).

To the contrary, Arambawela et al. (1975) found a higher incidence of diarrhea with cassava than with barley. Although there is some evidence that cyanide may be a contributory factor to digestive disturbances (Maner et al., 1967; Rajaguru et al., 1979), it is yet to be conclusively demonstrated. In the study reported by Arambawela et al. (1975), the incidence was reduced by restricted feeding of the cassava rations.

Chicco et al. (1972) substituted cassava meal for corn at levels up to 58.5% of a growing swine ration and found that gains were depressed only at levels of 40% and above. But there were no significant differences between any of the treatments in feed efficiency, organic matter digestibility and nitrogen retention. Similar results have been reported by Onaghise and Bowland (1977). Wyllie and Lekule (1980) found no significant differences in performance or carcass characteristics of swine fed a corn-based ration and those containing 18, 36 and 54% cassava meal. Khajarern et al. (1977) recommended that cassava meal can be used as a satisfactory replacement for corn provided that it is used at levels less than 50% for swine weighing up to 35 kg and 70% for heavier swine.

Although most workers have reported superior or comparable performance with cassava, in some studies even low levels of cassava have been found to noticeably depress the growth. Vellosa et al. (1967) observed that even 22% cassava meal in swine rations significantly depressed growth and feed efficiency. Maust et al. (1972a) replaced corn with 36% cassava meal and observed poorer performance and lower feed intake with swine fed cassava-based ration. Hew and Hutagalung (1977) gradually substituted corn with cassava meal, from 15 to 60%, in isonitrogenous rations and found a trend towards poorer performance with increasing levels of cassava. Feed intake was similar in all groups indicating that palatability was not a problem. However, in subsequent studies Maner and Gomez (1973) conclusively demonstrated that cassava meal can totally replace corn in swine rations provided the rations are properly balanced and adequately supplemented with methionine. In their trials, supplementation of cassava-soybean meal rations with 0.1-0.2% methionine significantly improved both the growth and feed efficiency and led to an increased urinary excretion of thiocyanate. Response from either level of supplementation was similar. Creswell et al. (1975) reported similar responses with 0.2% supplemental methionine. Hew and Hutagalung (1977) demonstrated that performance of swine fed rations containing more than 5% cassava meal could be significantly improved by the addition of 0.2% methionine. It appears that methionine serves both to overcome a deficiency of sulfur amino acids per se and as a readily available source of labile sulfur for cyanide detoxification (Maner and Gomez, 1973).

Methionine supplementation would be particularly beneficial when

cassava varieties high in cyanide are used in swine feeding. In this context, animal protein sources, especially fish meal, will be superior to vegetable proteins. Fish meal not only supplies methionine, but also spares it by providing vitamin B_{12} which serves as an independent pathway for cyanide detoxification (Oke, 1973). The potential value of fish meal in overcoming the growth depression caused by high levels of cassava has been demonstrated by several workers (Muller et al., 1975; Hew and Hutagalung, 1977).

Cassava meal is powdery in nature and there is evidence that this may lower the palatability (Khajajern et al., 1977). Henry (1971) reported that cassava-based rations when fed in a mash form appear to be disliked by swine. However, when pelleted they were in fact preferred to corn-based rations. Similar observations have been made by Muller et al. (1975), who concluded that pelleting eliminated irritation of the respiratory organs and eye infections thereby ensuring an optimum feed intake.

Limited information is available on the effects of cassava meal on the reproductive and lactation performance of swine. In an extensive study, Gomez (1979) found the litter size and weight at birth of gilts fed cassava meal to be somewhat comparable to those fed corn. However, the cassava-based ration apparently failed to support the lactation requirements resulting in a significantly lower litter size at 21 days.

CASSAVA FOR POULTRY

Early reports evaluating cassava meal as an energy source indicated that cassava meal should not be used at levels above 10% in rations for

young birds (Klein and Barlowen, 1954; Vogt, 1966; Yoshida et al., 1966). Vogt (1966) attributed the growth depression to incomplete removal of cyanide and to the possible presence of a phosphorylase inhibitor in the peels of cassava tuber. Yoshida et al. (1966) observed significant improvements in performance by soaking cassava overnight or by autoclaving at 120° C for one hour, indicating that residual cyanide was a problem in their cassava meal. Soares et al. (1968) substituted cassava meal for corn, in increments of 6%, up to a maximum of 42% of the ration. The rations were formulated to be iso-nitrogenous. Although there were no significant differences between the treatments, 12% substitution was found to be the best in terms of growth and feed efficiency. Job et al. (1980), using a cassava variety high in cyanide, observed significant depressions in weight gains and feed intake as the level of cassava was gradually increased from 5.7 to 28.5%. Their results suggested that cassava meal can be used at no more than 5.7% level in chick rations. While cyanide may have been a problem, failure to increase the protein and sulfur amino acid levels with increasing cassava substitution appears to be the major contributory factor for this depression.

Enriquez and Ross (1967) fed chicks with rations containing 0-50% cassava and found that cassava can be included up to 20%. The cassava meal used in their trials was artificially dried at 50° C for 24 hours and thus was low in cyanide. Montilla et al. (1969) incorporated cassava meal in rations at the levels of 0, 15 and 30% and reported the growth response of chicks to be similar in all treatments. A depression in feed intake was, however, observed with increasing levels of cassava

meal. Olson et al. (1969a) replaced corn with cassava meal in increments of 7.5% from 0 to 45%. All the rations were balanced to be iso-nitrogenous and iso-caloric by the addition of soybean meal and animal fat. Although there was a tendency to substitute cassava for cereals up to 45%, the performance of chicks fed more than 30% cassava meal favored corn-based rations. Thomas (1977) reported similar results with broilers.

The ability of birds to utilize cassava meal improves with age (Vogt, 1966; Khajarern and Khajarern, 1977). This may be due either to a decreasing requirement for sulfur amino acids or to an increase in the tolerance to the cyanide with age (Oke, 1978). Ademosun and Eshiett (1980) demonstrated that the optimum cassava level in starter rations was 15% and that this could be increased to 30% for growers and up to 40% for layers with no adverse effect on performance.

Enriquez and Ross (1972) fed a ration containing 50% cassava meal to growing birds. Although they observed a significant decrease in weight gains, it had no significant effect on their subsequent laying performance. In the same study, they demonstrated that cassava meal could be included up to 50% in layer rations without any adverse effects. Hamid and Jalaludin (1973) substituted cassava meal up to 60% in layer rations and obtained comparable performance to that of corn-based control. On the contrary, some studies have shown that 50% cassava level tends to decrease egg production and feed efficiency (Jalaludin and Leong, 1977; Khajarern et al., 1979).

Diets based on cassava meal may benefit from supplemental methionine. Enriquez and Ross (1967) supplemented the chick rations with 0.15-0.20% methionine and observed no ill effects even when cassava meal

constituted 50% of the ration. Similarly, Olson et al. (1969b) overcame the depressing effects observed with rations containing 45% cassava meal by the supplementation of 0.20% methionine.

The energy of cassava meal is efficiently metabolized by poultry. Metabolizable energy values reported for cassava meal range from 3.23 to 4.31 kcal/g (Table 3), which are comparable to that of corn samples from tropical regions (Muller et al., 1975).

Reduction in feed efficiency has been observed when cassava-based rations are used (Thomas, 1977; Ademosun and Eshiett, 1980), and this may be attributed to the powdery and dusty nature of cassava meal. Dustiness of cassava meal not only results in feed wastage which in turn could increase apparent feed intake (Ademosun and Eshiet, 1980), but also reduces performance by causing irritation in the respiratory tract of the birds (Muller et al., 1975). Thus, the beneficial effect of fat supplementation in poultry rations based on cassava meal (Ng and Hutagalung, 1974) may have been partly due to the reduction in dustiness. Pelleting also overcomes the problem of dustiness, and it has been shown that pelleted cassava meal can be used up to 60% in broiler rations (Khajarern et al., 1979) and up to 75% in replacement pullet rations (Muller et al., 1975).

A decline in the intensity of yellow pigmentation has been observed in broiler skin (Thomas, 1977) and egg yolk (Enriquez and Ross, 1972; Hamid and Jalaludin, 1972), when cassava meal was substituted for corn. However, this could be easily corrected by the inclusion of leaf meals or synthetic carotenoids in the rations (Agudu, 1972).

The literature on the use of cassava meal in poultry rations thus

TABLE 3. METABOLIZABLE ENERGY VALUES OF CASSAVA TUBER MEAL FOR POULTRY

Source	ME_n values (kcal/g DM)
Olson et al., 1969b (Brazil)	3.44
Hutagalung et al., 1974 (Malaysia)	3.23
Mueller et al., 1975 (Singapore)	3.65
Fetuga and Oluyemi, 1976 (Nigeria)	3.78
Aquirre et al., 1979 (Mexico)	3.20
Maust et al., 1972b (Thailand)	4.31

gives an inconclusive picture. Since most of the studies reviewed employed nutritionally balanced treatments, the variability in the cyanide content of cassava meal appears to be the important attribute causing these conflicting results. Proper detoxification of cassava tubers and supplemental methionine would alleviate this problem. Dustiness is certainly a limiting factor in cassava-based rations, and in this context, pelleting has been proven beneficial.

CASSAVA LEAF MEAL

The protein content of cassava leaves is extremely high for a non-leguminous plant and this offers a new perspective for livestock and poultry development under the conditions of subsistence tropical farming. Crude protein values ranging from 16.7 to 34.1% has been reported for cassava leaf meal (Table 4). The variability is probably related to the variety (Rogers and Milner, 1963), stage of maturity at harvest, sampling procedure, climate and soil fertility (Moore, 1976).

The yield of cassava leaves, depending on variety and soil fertility, may vary from 2000-8000 kg dry matter per hectare (Oke, 1978). The fact that this valuable feedstuff is presently wasted or used as manure further demonstrates the obvious economic advantage of its use in animal feeding. However, the negative correlation which exists between tuber and forage yields (Ahmed, 1973) should be born in mind, and methods must be developed to allow for harvesting of cassava leaves while maintaining reasonable yields of tuber. Ahmed (1973), using a ten-week harvesting frequency, obtained 6500 kg leaf dry matter/ha/year and reported that this reduced the tuber yield to almost one-half of the normal yield.

TABLE 4. PROXIMATE COMPOSITION OF ALFALFA LEAF MEAL AND CASSAVA LEAF MEAL (DRY MATTER BASIS)

	Alfalfa Leaf Meal[a]	Cassava Leaf Meal				
		1[b]	2[c]	3[d]	4[e]	5[f]
Crude protein	20.0	25.8	27.3	34.1	16.7	24.9
Ether extract	3.5	7.6	10.5	6.3	7.9	7.0
Crude fiber	21.0	7.9	4.8	10.7	17.2	21.7
Ash	10.5	8.8	5.7	6.2	12.5	6.8
Nitrogen-free extract	45.0	50.1	51.9	42.7	45.7	39.6

[a]Hubbell, 1980 (North America)
[b]Roger and Milner, 1963 (Jamaica)
[c]Roger and Milner, 1963 (Brazil)
[d]Eggum, 1970 (Nigeria)
[e]Ross and Enriquez, 1969 (El Salvador)
[f]Rajaguru, 1979 (Sri Lanka)

TABLE 5. AMINO ACID COMPOSITION OF ALFALFA LEAF MEAL AND CASSAVA LEAF MEAL (g/16 g N)

	Alfalfa Leaf Meal[a]	Cassava Leaf Meal		
		1[b]	2[c]	3[d]
Aspartic acid	-	10.14	9.63	9.77
Threonine	3.81	4.92	4.73	4.39
Serine	3.81	5.16	4.60	4.55
Glutamic acid	-	10.22	10.12	12.32
Proline	4.29	4.64	5.40	-
Glycine	4.76	5.39	5.32	4.86
Alanine	-	5.98	6.19	5.73
Valine	4.76	5.73	5.58	5.56
Cysteine	1.19	1.37	1.04	1.40
Methionine	1.33	1.65	1.71	1.86
Isoleucine	4.05	5.01	4.84	4.50
Leucine	6.67	8.89	8.85	8.19
Tyrosine	2.86	4.18	3.93	4.04
Phenylalanine	4.29	5.82	5.53	5.42
Lysine	4.57	7.20	6.33	5.87
Histidine	1.71	2.23	2.56	2.30
Arginine	4.57	5.28	6.12	5.34
Total	52.67	93.81	92.48	86.10

[a]Hubbell, 1980 (North America)

[b]Roger and Milner, 1963 (Jamaica)

[c]Roger and Milner, 1963 (Brazil)

[d]Eggum, 1970 (Nigeria)

Normanha (1962) harvested 9000 kg dry matter/ha in two cuttings over a two-year period and still produced within 30% of the normal yield of tubers. Dahniya et al. (1981) recommended a harvesting frequency of two or three months to ensure reasonable yields of both leaves and tubers.

Rogers and Milner (1969) were probably the first to determine the amino acid content of cassava leaves. They analyzed the leaves of 20 Jamaican and Brazilian cultivars obtained from ten-month old healthy cassava plants and reported that cassava leaf protein was deficient in methionine, possibly marginal in tryptophan but rich in lysine. Later studies (Eggum, 1970; Luiza et al., 1979) on cassava leaf protein showed similar amino acid patterns, although considerable variability was observed for individual amino acids. The amino acid profile of cassava leaf meal (CLM) compares favorably with that of alfalfa leaf meal (Table 5) but richer in lysine.

The digestibility of cassava leaf protein has been reported to be low ranging from 67% in mature leaves (Luyken et al., 1961) to 81% in young leaves (Eggum, 1970). Oke (1978) attributed the low protein digestibility values to the high fiber content of CLM. The nutritional availability of individual amino acids were studied by Eggum (1970) in rat bioassays. The availability of amino acids varied widely ranging from 55 to 84%. Only 59% of the methionine was biologically available, resulting in a very low biological value of 49 to 57%. Supplementation with methionine improved the biological value to 80%.

Although the protein value of cassava leaves is well documented, the cyanogen content had been a deterrent to their use as an animal feed. The leaves are rich in cyanogenic glucosides and may contain up

to 622 ppm in some varieties (Chew, 1972). However, this should not be a serious concern, since sun-drying eliminates most, if not all, of the cyanide (Obregon, 1968; Rajaguru et al., 1979).

CLM IN SWINE FEEDING

Limited information exists regarding the use of CLM in swine feeding. Mahendranathan (1972) replaced a basal growing swine ration with 50 and 75% fresh cassava tops and observed depressed performance. Lee and Hutagalung (1972) found that inclusion of 10 and 20% cassava leaves reduced palatability and decreased gains and feed efficiency in growing and finishing swine. The poor performance observed by these workers was apparently due to the high cyanide content of the fresh cassava leaves used in their trials. This hypothesis was confirmed in a subsequent study by Lee and Hutagalung (1972). They showed that the performance of swine fed cassava leaves can be improved by the addition of either 0.2% methionine or 0.15% sodium thiosulfate, indicating that the additional sulfur was used in the detoxification of cyanide.

Rajaguru et al. (1979) substituted sun-dried CLM for coconut oil meal at levels up to 30% in growing and finishing swine and found no adverse effects on performance. In fact, inclusion of CLM significantly improved the performance of growing swine over the coconut oil meal based ration, which was attributed to the high lysine content of CLM.

CLM IN POULTRY RATIONS

Ross and Enriquez (1969), in a series of trials, investigated the possible use of CLM in chick rations. They substituted CLM for alfalfa

meal up to 20% and observed progressively greater growth depression with increasing levels of CLM. However, supplementing the rations containing 20% CLM with 0.1% methionine and 3% corn oil resulted in performance comparable to the control. It was suggested that methionine is the first limiting factor and energy a second in the use of CLM. Addition of 0.15% sodium thiosulfate, a known sulfur donor, to the 20% CLM ration significantly improved the chick performance, indicating that the beneficial effect of supplemental methionine was through the provision of sulfur for the detoxification of cyanide which was determined to be 73 ppm in the CLM ration. The meal used in these trials was prepared by oven-drying the leafy materials overnight at 50° C.

Rajaguru (1979) evaluated sun-dried CLM as a replacement for coconut oil meal in broiler rations and concluded that it can be used up to 20% without any adverse effects. No supplemental methionine was necessary as the CLM ration contained only 7 ppm cyanide. Thus, if properly detoxified and supplemented, CLM would have a good potential as a source of protein in poultry rations. Similar observations have been made by Siriwardene and Ranaweera (1974). These workers determined the metabolizable energy content of CLM to be 1.92 kcal/g. An added advantage of incorporating CLM in poultry rations is its high xanthophyll content (605 mg/kg) which gives desirable color to the broiler skin and egg yolk (Agudu, 1972).

SESAME OIL MEAL

Sesame oil meal (*Sesamum indicum* L.), the residue remaining after extraction of oil from sesame seeds, is a valuable protein supplement in

tropical regions. Wide ranges have been reported for the crude protein content of sesame oil meal (SOM), and this may vary between 30 (Rajaguru, 1977) and 67% (Villegas et al., 1968) depending on the sesame variety and oil extraction method. Lease and Williams (1967) analyzed SOM from five different varieties and found the crude protein content to vary from 41 to 58%. SOM is known to be a good source of methionine but deficient in lysine (Kik, 1960; Villegas et al.,1968). Smith and Scott (1965) found a low level of free lysine in the plasma of sesame-fed chicks and concluded that lysine is the first limiting amino acid in SOM. SOM is rich in calcium and phosphorus and highly palatable (Weiss, 1971).

Lysine deficiency limits the use of SOM as the sole protein supplement in non-ruminant rations. Grau and Almquist (1944) found that chicks fed a basal ration containing 20% protein supplied from SOM showed poor growth. Growth response was improved when the sesame-based ration was supplemented with 0.5% lysine.

Soybean meal protein is deficient in methionine, whereas SOM protein contains 1.22% methionine (Weiss, 1971). SOM can, therefore, be a valuable supplement to soybean meal in non-ruminant rations. This was demonstrated by Almquist and Grau (1944), who fed soybean meal, SOM and combinations of these two to chicks at a level which supplied 20% protein. Best gains were obtained at the SOM/soybean meal ratio of 7:13. However, Cuca and Sunde (1967b) reported that a ratio of 9:25 was sufficient to support satisfactory growth of chicks.

Daghir et al. (1967) showed that SOM may replace up to 50% of the soybean meal in broiler rations. Supplementation of the SOM-based

ration with 0.5% lysine significantly improved the weight gain and efficiency. It was concluded that, in addition to lysine, SOM is deficient in some unknown factor(s) found in soybean meal. Similar suggestions have been made by several other workers (Patrick, 1953; Cuca and Sunde, 1967b). Responses to threonine supplementation have also been reported (Kik, 1960; Cuca and Sunde, 1967b), indicating that threonine may be the second limiting amino acid in SOM-based rations. Based on plasma analysis, Smith and Scott (1965) have reported that threonine is apparently deficient in SOM.

SOM contains high amounts of phytate and oxalate (Toma et al., 1979) and these compounds may interfere with the mineral availability of the rations. Phytates have been implicated in reducing the availability of calcium, zinc, iron and phosphorus (Spiller and Shipley, 1976). Lease et al. (1960) showed that chicks fed a SOM-based ration developed leg deformities similar to those reported in zinc deficiency, even though they received adequate amounts of zinc in the ration. Addition of 60 ppm zinc was found to improve growth rate and greatly reduce the leg deformities. In a subsequent study (Lease, 1966), autoclaving SOM for two hours decreased leg abnormalities and improved growth response. The phytic acid content of the meal, however, was not measurably decreased. It was suggested that zinc may be held by several bonds to the phytic acid and that autoclaving may break some of the bonds, thus making the zinc available.

Cuca and Sunde (1967a) studied the calcium availability of SOM and reported that calcium from corn-sesame ration was not as available as the calcium from corn-soybean ration. In addition to phytate, oxalate

is also known to lower the availability of calcium in the feeds (Oke, 1970.

The high cost of SOM precludes its use in swine rations, even in the areas of primary production, and this is evidenced by a lack of published information. Gallo and Maner (1970) replaced soybean meal with SOM at the levels of 5 and 10% and found no differences between the treatments.

COCONUT OIL MEAL

Coconut oil meal (COM), the residue from extraction of oil from the dried endosperm of the coconut (*Cocos nucifera L.*), is available throughout much of the tropics. Even though the meal contains only moderate levels of protein, it represents the widely used and economically important source of protein in many areas.

COM contains between 23 and 29% crude protein, about 6-10% ether extract and about 10-17% crude fiber (Grieve *et al.*, 1966; Owusu-Domfeh *et al.*, 1970; Creswell and Brooks, 1971a). The variations in composition are apparently related to the method of extraction employed. The amino acid composition of COM has been studied by several workers (Creswell and Brooks, 1971a; Mee and Brooks, 1973). COM protein has the same level of sulfur amino acid as soybean meal but contains low levels of lysine, isoleucine, leucine and histidine. The various nutrient components of COM are well digested by swine, except for the protein fraction. Creswell and Brooks (1971a) reported that expeller-extracted COM had digestibility values of 84, 100, 85, 94 and 51% for dry matter, ether extract, energy, nitrogen-free extract and crude protein, respectively.

To the contrary, Loosli et al. (1954) found the crude protein fraction to be 73% digestible. In studies with mice, Owusu-Domfeh et al. (1970) determined the protein digestibility to be 63%. The disagreements in protein digestibility may have been due to the differences in processing temperature. Samson (1971) demonstrated reduced solubility of COM protein when it is subjected to temperatures of more than 120° C for 15 minutes. Butterworth and Fox (1963) heat treated COM for 30 minutes from 40 to 150° C and observed a progressive decline in protein digestibility with each increase in temperature.

Mee and Brooks (1973) compared the amino acid availability of COM protein with that of corn-soybean protein. The availability and true digestibility of most amino acids were found to be significantly lower in COM protein. Availability of lysine, in particular, was extremely low. The low amino acid availability is probably due to the denaturation of proteins at high processing temperatures. Reduction in available lysine with increasing processing temperatures has been shown by several workers (Butterworth and Fox, 1963; Samson, 1971).

Although COM is sometimes used up to levels as high as 70% in poultry and swine rations in some tropical areas (Rajaguru et al., 1978), surprisingly little published information is available to justify its high level of usage. Grieve et al. (1966) studied the effects of 10, 20 and 30% COM in growing and finishing swine rations and found no differences between the soybean meal-based control and the treatment rations in terms of gain, feed efficiency and carcass quality. They recommended that COM can be used successfully up to 30% to supply both the protein and energy in swine rations. COM has been reported to

contain a high digestible energy value of 3.60 kcal/g (Creswell and Brooks, 1971a).

Malynicz (1973) reported slight depressions in gains when COM was included at 20 and 30% in swine rations. Creswell and Brooks (1971b) found that dietary levels of up to 20% COM caused only slight depression in the performance of growing and finishing swine, but 40% inclusion resulted in 40 and 30% reductions in gains and feed efficiency, respectively. In the same study, increased protein level and supplementary lysine were without effect when added to rations containing 20 or 40% COM. It was suggested that some factor other than a lack of adequate protein or lysine is responsible for the growth depressing effects of COM.

COM may be considered as a good source of protein for growing chicks when it forms 15 to 20% of the total ration (Fronda and Mallonga, 1935). Temperton and Dudley (1941) reported that COM may constitute up to 20 to 25% of the poultry ration without any adverse effects. Fronda (1919) demonstrated that, as a sole protein supplement, COM was not effective in supporting egg production in layers. Best results were obtained when COM constituted not more than 20% of the layer ration.

RUBBER SEED MEAL

Rubber seed meal (*Hevea brasiliensis*) is a by-product resulting from the industrial extraction of oil from rubber seeds. Although the potential uses of rubber seed have been known for almost a century (Anon, 1903), the interest to utilize rubber seed meal (RSM) in animal feeding is of recent origin. Hence, studies on the nutrient composition

and use of RSM are limited both in number and scope.

Crude protein values ranging from 23.6 (Buvanendran and Siriwardene, 1970) to 36.5% (Fetuga et al., 1977) have been reported for RSM. An analysis of the available composition data (Buvanendran and Siriwardene, 1970; Siriwardene and Nugara, 1972; Oluyemi et al., 1976; Fetuga et al., 1977) reveals that the variations in the crude protein are closely associated with the variations in the crude fiber, samples with a high crude protein content having a low crude fiber and vice versa. Thus, it would appear that the crude protein content of the RSM is a reflection of the efficiency of dehulling of the seed prior to oil extraction. The hull weighs 43% of the unhulled rubber seed (Orok and Bowland, 1974b) and often are not removed completely by the commercial producer in an attempt to improve the efficiency of oil extraction.

Rubber seed protein is a moderately good source of essential amino acids (Lauw et al., 1967; Orok and Bowland, 1974b; Fetuga et al., 1977). It is, however, deficient in lysine and sulfur amino acids. RSM contains fairly high levels of Ca, P, Zn and Cu (Fetuga et al., 1977).

The presence of a cyanogenic glucoside in RSM has been reported (Bredemen, 1931), but this appears to be destroyed by the high temperatures during oil extraction (Le-Thuoc, 1968) and during storage (Georgi et al., 1932). No toxic effects of feeding RSM or rubber seeds have so far been reported. Buvanendran and Siriwardene (1970) observed 20% mortality when layers were fed a ration containing 25% RSM, but post-mortem examination failed to reveal any specific causes for the mortality.

Buvanendran and Siriwardene (1970) evaluated RSM as a substitute

for coconut oil meal in poultry rations. They found that RSM could be incorporated in broiler and layer rations up to 20 and 25%, respectively. Similar results have been reported by other workers (Rajaguru and Wettimuny, 1971; Ong and Yeong, 1977). Rajaguru (1971) fed rations containing 0, 10, 20, 30 and 40% RSM to replacement pullets and noted that the birds on RSM rations matured late. RSM had no effect on the egg production but decreased the egg size and shell thickness. Increasing levels of RSM were found to increase the percentage of infertile eggs, thus lowering hatchability. It was recommended that RSM could be included up to 20% in layer rations but should be avoided in breeder rations. Similar anti-fertility effects with increasing levels of RSM have been reported by Buvanendran (1971). It appears that RSM has no effect on the semen quality of male birds (Rajaguru, 1971).

Oluyemi et al. (1976) determined the metabolizable energy value of RSM for poultry to be 2.46 kcal/g, whereas a lower value of 1.79 kcal/g was reported by Siriwardene and Nugara (1972). The difference was probably related to the difference in composition of the samples.

Ong and Yeong (1977) reported that levels of more than 15% RSM should not be used in rations for growing swine. These findings were confirmed by Rajaguru and Ravindran (1979), who observed progressive depression in gain and feed efficiency when RSM was increased above 10% level in growing swine rations. Poor performance of swine and poultry fed high levels of RSM has been attributed to the deficiencies of lysine and sulfur amino acids rather than to the presence of cyanogenic glucoside (Rajaguru, 1971; Rajaguru and Ravindran, 1979). Responses to

lysine and methionine supplementation in rations based on RSM (Fetuga et al, 1977) lends support to this hypothesis.

SWEET POTATO LEAF MEAL

The foliage of sweet potato plant (Ipomea batatas L.) yields approximately 2300 kg dry matter per hectare (Garlich et al., 1974). Although sweet potato vines are being fed to swine and cattle in some of the Southeast Asian countries, the current practice in most regions is to return this dry matter to the soil.

While the sweet potato leaf meal (SPLM) prepared from mature vines at the time of tuber harvest contains only around 10% crude protein, by practicing early harvesting leaf meals containing as high as 22.5% crude protein can be obtained (Garlich et al., 1974). The amino acid composition of SPLM protein has been studied by Walter et al. (1978). The essential amino acid profile, without exception, was remarkably similar to that of alfalfa leaf meal protein. The age of plant had little, if any, effect on the amino acid composition. Based on the amino acid composition, SPLM protein appears to be of high nutritional quality and may be a valuable supplement in animal feeding. Chen and Chen (1979) reported that SPLM contained 1.16% Ca, 0.21% P, 1.37% K, 0.41% Na, 0.31% Mg, 993 ppm Fe, 33 ppm Cu, 83 ppm Mn and 53 ppm Zn.

Data concerning the use of SPLM in swine and poultry rations are almost non-existent. If SPLM is to be used in poultry rations, its xanthophyll content would be of considerable importance. Garlich et al. (1974) evaluated SPLM as a source of xanthophyll pigment in broiler and layer rations. Their results suggest that SPLM can be used as both

a pigmentation agent and as a source of protein in poultry rations.

ENERGY SYSTEMS FOR POULTRY

Metabolizable energy (ME) has become the generally accepted method of expressing energy values of feedstuffs for poultry. ME is the difference between the gross energy of the feed consumed and the gross energies of the feces and urine. The excretion of feces and urine together in poultry makes the determination of ME technically simpler than digestible energy.

METABOLIZABLE ENERGY

Metabolizable energy corrected for nitrogen equilibrium (ME_n) has been the measure of available energy in feedstuffs for poultry, ever since Hill and Anderson (1958) showed that ME_n values are more reproducible than the previously used productive energy of Fraps (1946). General aspects and problems of ME_n determinations with poultry have been reviewed by Vohra (1972), Miller (1974) and Sibbald (1979b). An evaluation of the errors involved in measuring ME_n was presented by Potter (1972).

The classical ME_n assays are not only expensive and time consuming but also the data are reported to be highly variable depending on various factors including methodology, temperature, feed intake, strains, species and age of birds (Miller, 1974; Sibbald, 1978; Farrell, 1979; Sibbald, 1980a). Furthermore, according to Sibbald (1976a), ME_n values fail to correct for metabolic and endogenous energy losses.

TRUE METABOLIZABLE ENERGY

A rapid bioassay for true metabolizable energy (TME) determination of feedstuffs for poultry has been described by Sibbald (1976a). In this procedure, fasted adult roosters are force-fed a known quantity of feedstuff and the excreta voided during the subsequent 24 hours are collected quantitatively and assayed for gross energy. Within each replication, one bird remains unfed and provides an estimate of metabolic and endogenous energy losses. This correction controls variations due to differences in feed intake (Sibbald, 1975) and probably removes much of the variability among birds due to differences in age (Shires et al., 1980), and species, strains and sex (Sibbald, 1976b; Dale and Fuller, 1980).

Although the original TME bioassay (Sibbald, 1976a) was based on an excreta collection period of 24 hours, recent evidences suggest that residues of some feedstuffs may require more than 24 hours to clear the digestive tract and that, unless a collection period of more than 24 hours is used, TME values may be overestimated (Muztar and Slinger, 1979; Sibbald, 1979a,c; Sibbald, 1980b). In general, the slow rate of passage appears to be associated with the amount of indigestible material placed in the crop. Consequently, it is now proposed that, if TME values obtained with a 24-hour collection period are erratic, the excreta collection period be extended to 48 hours (Sibbald, 1979b and 1980a). However, for some feedstuffs such as oats, it may be necessary to collect excreta for 52 hours post force-feeding (Sibbald, 1980b).

Since only a small quantity of feedstuff is force-fed, the TME

value is extremely sensitive to the amount of endogenous excreta voided by the "paired" fasted roosters. This was cited as the principal drawback of the TME bioassay by Farrell (1981), who critically assessed this method and concluded that "There is no sound reason for changing to a TME system at the present time." Although it is not related to body weight (Sibbald and Price, 1978), there is substantial evidence to show wide variation in the day to day output of endogenous excreta for an individual starved rooster (Farrell, 1978; Sibbald and Price, 1980) and variations between roosters (Sibbald, 1976c; Sibbald and Price, 1978). Part of this variability may arise from the contamination of excreta with external scurf that is constantly shed and is inseparable from the endogenous excreta (Farrell, 1979). An experimental design which reduces this variability was proposed by Edmundson et al. (1978), in which each bird is used to serve as its own control, involving two sequential collections. Sibbald and Price (1980), however, considered the advantages of this design to be minimal with respect to time inconvenience and cost.

Farrell (1981) reported that ration composition, particularly NDF content, may influence the amount of endogenous excreta, and it is therefore inappropriate to apply the same single value from starved cockerels for all feedstuffs. Another factor which strongly influences endogenous energy excretion by starved birds is ambient temperature (Farrell and Swain, 1977; Dale and Fuller, 1981). The excretion was higher during the colder months, presumably reflecting increased tissue metabolism resulting from a high energetic maintenance requirement.

The potential usefulness of TME bioassay over the ME_n assay, as

discussed in a recent review by Sibbald (1980a), is based primarily on its simplicity and rapidity. It is inexpensive, requires only a 200 g feed sample and provides results within a few days of receipt of feed ingredients. Dale and Fuller (1981), while maintaining satisfactory precision, further simplified the TME procedure by pooling the weighed, dried excreta samples prior to the gross energy assay.

TME assay produces data that are more reproducible than the ME_n assays. In a collaborative study involving nine laboratories, Sibbald (1978) observed a wide variability in ME_n data among laboratories for a sample of yellow corn, 17 mean ME_n values ranged from 3.08 to 4.03 kcal/g, whereas nine mean TME values ranged from 3.99 to 4.15 kcal/g. Furthermore, the practical applicability of TME values appear to be better than ME_n values. Engster et al. (1981) formulated rations isocaloric in ME_n but differing in TME and rations isocaloric in TME but differing in ME_n. When the rations were fed to broilers, there were responses to variation in TME when ME_n was constant, but variation in ME_n elicited no response when TME was constant. Another attractive feature of TME bioassay is that it can be extended to permit measurements of true available amino acids (Likuski and Dorrell, 1978), lipids (Sibbald and Kramer, 1980) and minerals (Sibbald, 1982). Thus, one TME bioassay can generate a considerable amount of information regarding the availabilities of several nutrients.

FIBER IN SWINE RATIONS

As conventional high energy cereal grains progressively become expensive and decreasingly available for animal feeding, search for alter-

nate feed sources becomes imperative. In this context, the use of fibrous feed sources in swine rations may be expected to increase in the future. This realization is well reflected by a revival of interest in the utilization of fibrous feedstuffs during the recent years.

BASIS OF UTILIZATION

The ability of swine to digest and utilize fibrous feeds is generally recognized to be lower than in ruminants. Although fiber was formerly thought to be of little nutritional significance, current evidence suggests that its value for swine has been underestimated. The colon and cecum of swine are inhabited by microflora capable of hydrolyzing and fermenting cellulolytic material and yielding volatile fatty acids (VFA) that can be utilized for energy (Rerat, 1978). The fiber-fermenting bacteria present in the lower digestive tract are obligate anaerobes and are identical to those found in the rumen or cecum of herbivores (Van Soest and Robertson, 1977).

Sambrook (1979) studied the disappearance of acid detergent fiber fraction in the gastrointestinal tract of swine fitted with duodenal, midjejunal and ileal canulas and found substantial disappearance on passage through the large intestine. Keys and DeBarthe (1974) reported that 100% of the cellulose and 80% of the hemicellulose digestion occurred in the large intestine. The transport of VFA through the colonic and cecal mucosa of swine is very efficient (Argenzio and Southworth, 1975) and apparently complete (Farrell and Johnson, 1972). This fact is also supported by the occurrence of VFA in the pheripheral blood during digestion (Friend et al., 1964). Imoto and Namioka (1978b) showed that a

major portion of VFA from the large intestine is metabolized during absorption, and consequently the VFA circulating in the pheripheral blood appears to be primarily of endogenous origin.

While the VFA could be a significant source of energy, studies on the degree to which they are utilized by swine are limited and contradictory. Friend et al. (1964) estimated the potential energy contribution by VFA to be between 15 and 28% of the maintenance energy requirement of the swine. Kass et al. (1980b) reported that the VFA can provide from 5 to 14% of the energy required for the maintenance. Variability observed by these workers was attributed to differences in the crude fiber level and age of swine. Imoto and Namioka (1978a) fed swine with two levels of carbohydrate and found that the VFA absorbed in the large intestine accounts for 11.6 and 9.6% of the metabolizable energy for maintenance for the low carbohydrate and the high carbohydrate groups, respectively.

Farrell and Johnson (1972) determined the energy controbution of VFA, produced in the cecum of 40 kg growing swine, to vary between 3.8 and 6.1% of the maintenance energy requirement depending on the crude fiber content of the diet. They concluded that the cecum plays only a minor role in the breakdown of fibrous feedstuffs.

The source of dietary fiber may also be a determinant causing variations in the potential energy contribution through VFA. In studies with sunflower hulls, Gargallo and Zimmerman (1981) found that VFA contributed about 8% of the energy required for maintenance. However, this was independent of the dietary sunflower hull level indicating that sunflower hulls do not have any energy value for swine.

The reported values for the digestiblity of crude fiber by swine range from zero to over 97% (Rerat, 1978). Much of the variability observed may be attributed to differences in source of fiber (Forbes and Hamilton, 1952), level of fiber (Kornegay, 1978), level of feeding (Cunningham et al., 1962), age of the animal (Henry and Etienne, 1969) and the nature of the non-fibrous portion of the ration (Myer et al., 1975; Imoto and Namioka, 1978a). Some of the factors contributing to the variability in crude fiber digestion have been reviewed by Rerat (1978).

USE OF HIGH FIBER RATIONS

The inhibitory effect of high levels of dietary fiber on the growth rate of growing-finishing swine is well documented (Bowland et al., 1970; Campabadal et al., 1976, Kornegay, 1978; Kass et al., 1980a; Kornegay, 1981). Fibrous feeds differ in their growth depressing effects in swine, and these differences have been attributed, in general, to the chemical variation within the fiber and, in particular, to the degree of lignification (Pond and Kass, 1977). Considerable individual variation is also known to exist among swine in their ability to utilize fiber (King and Taverner, 1975).

Energy dilution resulting from the substitution of fibrous feeds at the expense of high energy cereals is probably the major factor limiting the high level usage of fiber in swine rations. Several workers (Baird et al., 1970 and 1975; Cole et al., 1967b) have reported that fiber per se is not necessarily responsible for depression in performance but rather the reduced energy content of the high fiber rations. It was also

demonstrated that swine can tolerate wide ranges of crude fiber provided the energy density of the ration is adequate. Baird et al. (1975) presented evidence to suggest that swine eat to satisfy an energy requirement provided that the appetite is not limited by bulk or palatability. A tendency to increase daily feed intake with high dietary fiber levels has been reported by several workers (Baird et al., 1970 and 1975; Cole et al., 1967a,b; Kornegay, 1978; Kass et al., 1980a).

The depressing effects of high levels of crude fiber on the digestibilities of other nutrients in the ration have been demonstrated repeatedly (Cunningham et al., 1962; Pond et al., 1962; Henry and Etienne, 1969; Bowland et al., 1970; Keys and DeBarthe, 1974; Campabadal et al., 1976; Kornegay, 1978, Kass et al., 1980a; Sherry et al., 1981). The effect of crude fiber on its digestibility has been varied. Rerat (1978) reported that a rise in the crude fiber level of the ration only slightly affects its digestibility. Keys et al. (1970) found that increasing the dietary cell wall content had no effect on the digestibility of cellulose and cell wall but reduced the hemicellulose digestibility. In trials with sows, Pollmann et al. (1979) observed a decreasing trend in the digestibility of fiber components with increasing levels of dietary fiber, which also varied with the source of fiber. To the contrary, Kornegay (1978) reported an increase in the digestibilities of acid detergent fiber, cellulose and lignin as soybean hulls were incorporated at levels of 15 and 30% in swine rations. There was a trend for crude fiber digestion to increase, while the digestion of cell walls and hemicellulose was unaffected.

Increased fecal N excretion with increasing levels of crude fiber

has been shown by several workers (Whiting and Bezeau, 1957; Meyer, 1956; Fahey et al., 1980). Farrell (1973) and Mason et al. (1976) attributed this increase in fecal N to an increase in the nitrogen of bacterial origin, a result of increased bacterial activity on high fiber rations. This view is supported by the findings of Whiting and Bezeau (1957), who reported increased metabolic fecal N with high dietary fiber levels. Crude fiber is also considered to cause increased fecal N loss in animals presumably through mechanical abrasion of the digestive tract (Muztar and Slinger, 1980). Thus, a decrease in true nitrogen digestibility apparently does not occur. Other workers (Kass et al., 1980a; Sherry et al., 1981), however, have reported no such effect in fecal N due to the level of fiber.

Reports on the effects of fiber on N retention are inconsistent. While some have reported improved N retention (Likuski et al., 1961; Kornegay, 1978; Corley et al., 1978), others have found no significant effect due to high fiber levels (Henry and Etienne, 1969; Fahey et al., 1980). Likuski et al. (1961) found that N retention as a percentage of gross or digested N was lower for a high fiber-low energy ration than for a low fiber-high energy ration. Kornegay (1978) substituted soybean hulls in a corn-soybean basal ration and noted that N retention as a percent of N intake was not affected, while N retention as a percentage of digested N was increased as hulls were increased. Corley et al. (1978) reported a 28% increase in N retention of growing swine when 4% Solka Floc was added to a corn-soybean ration. In the same study, when swine were fed with acid-hydrolyzed alpha-cellulose rations, the N retention was found to be poorer, suggesting that factors other than the

cellulose stimulate N retention. McLaren et al. (1976) proposed that these factors could be either hemicellulose, phenolic-carbohydrate complexes or some of their breakdown products. This hypothesis is supported by earlier research (McLaren et al., 1974), which showed increased N retention in rats fed an acid-resistant fraction of hemicellulose derived from corn cobs and alfalfa.

MECHANISM(S) OF ACTION

The mechanism(s) by which high levels of fiber affects the apparent digestibility of other dietary constitutents is far from clear at the present time. Fiber may have certain physiochemical effects that change enzymatic activity or bind digestion products and hinder their absorption (Spiller and Shipley, 1977). Fiber components, particularly lignin (Eastwood and Hamilton, 1968) and hemicellulose (Story and Kritchevsky, 1976) have been implicated in the binding of bile acids. Bile salts are important for the activity of pancreatic lipase, but they also have a role in the regulation of proteolytic activity in the intestine by virtue of their regulation of enterokinase activity (Spiller and Shipley, 1977). The binding of bile salts to dietary fiber could, theoretically, influence the activity of pancreatic enzymes. Positive evidence supporting this hypothesis was presented by Schneeman and Gallaher (1980), who found that feeding rats with semipurified rations containing 20% Solka Floc caused a reduction in the activities of trypsin, chymotrypsin, amylase, lipase and protease in the intestine.

Murray (1976) suggested that the deleterious effects of fiber might be due to gel-forming polysaccharides such as pectin, which prevent the

contact between digestive enzymes and nutrients. Another way by which the fiber affects nutrient digestibility is by increasing the rate of passage of digesta through the digestive tract (Kass et al., 1980a).

EFFECT ON RATE OF PASSAGE

Increasing the level of fiber in rations has been reported to result in a faster rate of passage of digesta (Kass et al.,1980a). With a faster rate of passage, there would be less opportunity for digestion and this could account, at least in part, for the depressing effect of fiber on nutrient digestibility.

It is generally accepted that the laxative effect of fiber is caused primarily by the mechanical stimulus of distention due to the presence of large amounts of residue in the colon and enhanced by the waterholding capacity of the biopolymers involved (Monte, 1981). Other factors that seem to enhance the "water holding" capacity of fiber is its association with organic anions. Accumulated anions due in part to their poor lipid affinity at colonic pH are postulated to counteract water reabsorption by the colon. The increased water content of the feces as a result of fiber addition is well established in swine (Cooper and Tyler, 1959 a,b; Kornegay, 1978; Kass et al.,1980a).

Williams and Olmsted (1936) postulated that VFA or other products of fiber degradation may also act as chemical stimuli contributing to the faster rate of passage. Fioramonti and Bueno (1980) studied the motor activity of large intestine of swine and found that addition of fiber resulted in long spike bursts which are associated with propulsion of intestinal contents.

EFFECTS ON MINERAL AVAILABILITY

An important and controversial issue concerning the use of fibrous feeds in swine feeding centers upon the effects of fiber on the absorption of certain minerals. Although data on this subject are limited, research on other non-ruminant species indicate that fiber may have negative effects on the absorption of Ca, P, Zn, Fe, Mg (Spiller and Shipley, 1977), Cu and Mn (Davies and Nightingale, 1975).

Phytate was the first fiber component to be implicated with reduced mineral availability (McCance and Widdowson, 1942). Recent studies show that other fiber components including cellulose (Ismail-Beigi et al., 1977), hemicellulose (Kies et al., 1979; Mod et al., 1981) and gel-forming polysaccharides (Harmuth-Hoene and Schelenz, 1980) all individually influence mineral utilization.

ANTIBIOTIC X FIBER INTERACTION

The use of antibiotics as additives in swine ration has been extensively studied (Hays, 1981). Their modes of action have also been subject to several reviews during the recent years (Visek, 1978; Hays, 1981; Henderickx et al., 1981).

It is generally accepted that the effects of antibiotics upon animal performance is primarily initiated by modifications of the enteric flora. It is, therefore, possible that antibiotics may alter the passage rate and nutrient digestibility through their influence on microorganisms. However, available information on this potential relationship are conflicting. Evans and Maguire (1956) reported that penicillin and aureomycin had no bactericidal or bacteriostatis effects

on cellulolytic organisms in the large intestine of swine. Bohman et al. (1955) showed that aureomycin supplementation to the ration of growing-finishing swine fed high levels of alfalfa had no effect on the ability of swine to utilize the energy of the ration. Brown et al. (1951) detected no change in the rate of passage of digesta in swine following aureomycin supplementation. To the contrary, Forbes and Hamilton (1952) observed that inclusion of sulfathalidine resulted in significant reductions in crude fiber and cellulose digestibility in swine. Gargallo and Zimmerman (1980) infused neomycin into the cecum and observed a complete cessation of cellulose digestion.

Sherry et al. (1981) reported that Aureo-SP 250[1] supplementation had no effect on the cellulose or energy digestibility in growing swine. Conversely, Gorrill et al. (1960) found an improvement in energy digestibility following the supplementation of a mixture of penicillin, streptomycin and aureomycin. It appears that the effect of antibiotics on cellulolytic microorganisms and cellulose digestion depends on many factors including the source and level of antibiotics (Sherry et al., 1981).

Virginiamycin, an antibiotic developed solely for use in animal feeding, has been recently shown to slow the rate of passage of digesta in swine (Fausch, 1981). This finding offers promise to counteract, at least to some extent, the faster rate of passage and to improve nutrient utilization in high fiber rations.

FIBER IN SOW RATIONS

Fibrous feedstuffs are traditionally used as laxatives in rations

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[1]Mixture of aureomycin chlortetracycline, sulfamethazine and penicillin.

for gestating and lactating sows. Available evidence suggests that the energy in fibrous feedstuffs are well utilized by sows. Boyd et al. (1976) showed that the metabolizable energy value of alfalfa for gilts and sows is 150% higher than reported by NRC (1973). The potential for fibrous feedstuffs as major sources of energy for gestating sows was demonstrated by Danielson and Noonan (1975), who fed gilts on rations containing 97% alfalfa meal for three successive generations with no adverse effects on farrowing performance. Similar results have been reported by Allee (1977).

Published information concerning the efficacy of fibrous feedstuffs on the reproductive performance of sows has been conflicting. While some workers (Baker et al., 1974; Teague and Grifo, 1965) have reported no effect on reproductive performance, beneficial effects including higher farrowing rate (Teague, 1955; Seerly and Wahlstrom, 1965; Danielson and Noonan, 1975), increased birth weights (Elsley et al., 1969; Frobish et al., 1973) and improved survival rate (Teague, 1955; Seerly and Wahlstrom, 1965; Pollmann et al., 1980) have been claimed by others. However, high level inclusion of fibrous feedstuffs to the gestation ration may result in decreased birth weights (Danielson and Noonan, 1975; Allee, 1977; Pollmann et al., 1980).

FIBER: PERSPECTIVES IN SWINE NUTRITION

In spite of the abundant literature available on the growth depressing effects of high fiber rations, it is now established that the growth of swine can be supported by wide ranges of crude fiber provided the energy density is sustained in the ration. A variety of fibrous

feedstuffs have been substituted in substantial amounts for cereal grains with no adverse effects on the growth of swine (Keys and DeBarthe, 1974; Cheeke, 1977; Kornegay, 1978; Peers et al., 1978; Collings et al., 1979; Kennelly and Aherne, 1980; Young, 1980; Kass et al., 1980a; Kornegay, 1981). Since the economic advantage of prudent substitution of fibrous feedstuffs is clearly evident, potential for their increased usage in the future looks promising.

Addition of fiber has also been claimed to enhance the gastrointestinal environment of pigs at weaning. Moser (1981) reported that addition of ground oats to the rations of early weaned pigs may act as a buffer against stress, thereby reducing the incidence of scours. Conversely, Kong et al. (1980) evaluated 0, 33 and 66% ground oats in rations for weanlings and concluded that high levels of ground oats had minimal effect on the incidence of scours. Wahlstrom et al. (1977) and Kornegay et al. (1980) also found no differences in fecal consistency when fibrous feedstuffs were included in starter rations.

There is some evidence to suggest that low level of inclusion of fiber may in fact be beneficial to the growth of early weaned (Real et al., 1977; Mateo et al., 1980) and growing-finishing swine (Kornegay, 1978). The role of fiber as a growth stimulant probably arises from its protective effect against the toxins that may be present in the feed or produced by the microbes in the digestive tract. Lang and Briggs (1976) reported that fiber could bind potential toxins, prevent their digestion or absorption and facilitate their excretion. The ability of alfalfa meal and other bulky materials to completely counteract the toxicity of non-ionic surface active agents has been

demonstrated by Ershoff (1960). Ershoff (1974) showed that differences exist in the ability of various biopolymers in fiber to counteract toxic substances.

Limited amount of data suggests that additional fiber may be beneficial during cool weather. Seerly et al. (1978) found the performance of growing-finishing swine on a high fiber ration to be poorer than those on a low fiber ration in summer, while the winter performance on these two rations to be similar. It was postulated that the higher heat increment associated with fiber fermentation reduces that amount of heat the animal has to generate metabolically to maintain body temperature during cool weather, thereby improving feed efficiency.

Evidence presented thus far suggests that utilization of moderate levels of fibrous feeds is physiologically plausible and economically desirable. However, it is essential to be aware of the nutritionally harmful effects that may be associated with fiber intake. Although the mechanism(s) involved are not clearly understood, it is generally accepted that the considerable variation that exists in the chemical composition and physiochemical properties of fibrous feedstuffs is the major contributing factor influencing nutrient bioavailability, particularly mineral availability, in the ration.

Manipulation of microbial activity by modifying the passage rate may lend promise to effectively maximize the use of fibrous feedstuffs in swine production. While research into ways of maximizing the use of fiber should continue, the interactions between different kinds of fiber and other nutrients need extensive investigations.

Chapter III

NUTRIENT CHARACTERIZATION OF SOME TROPICAL FEEDSTUFFS

INTRODUCTION

Much emphasis has been given to the expansion of the livestock industry of Sri Lanka during recent years. Due to the scarcity of traditional feedstuffs, considerable interest is being shown in the formulation of diets based on locally available, non-traditional feedstuffs. Although vast potential exists for increasing the supply of non-traditional feed resources, there is a paucity of published information on the nutrient composition and the limitations of their use in animal feeding. This lack of information has hindered efforts by nutritionists to utilize them effectively in feed formulation. Thus, it has been necessary to use information reported for feedstuffs grown in other countries to formulate local livestock diets. This has been most notably the case as regards mineral and amino acid composition. While such information could serve as a guide, it is inadequate for accurate diet formulation. Interactions of climate, soil, species and other factors could cause appreciable differences in nutrient composition between locally grown feedstuffs and those grown in other countries under, perhaps, different conditions. The study reported herein was undertaken to characterize the nutrient composition of six Sri Lankan feedstuffs, which could be utilized in balancing local livestock diets.

MATERIALS AND METHODS

Origin and Preparation of Materials. Six feed ingredients, namely

coconut oil meal, sesame oil meal, rubber seed meal, cassava tuber meal, cassava leaf meal and sweet potato leaf meal were air-shipped from Sri Lanka in May of 1980. Upon arrival at Blacksburg, U.S.A., individual feedstuffs were mixed well and representative samples were taken for nutrient analysis. The ingredients were then stored in sealed polyethylene bags at 5 C until used.

Cassava tubers, cassava leaves and sweet potato leaves were obtained from the experimental plots of the Department of Animal Husbandry, University of Peradeniya, Peradeniya. The cassava tubers and leaves were from the variety MU 22. Cassava tuber meal was prepared from fresh unpeeled cassava tubers. Tubers were chopped into .63 cm thick slices and dried in a unitherm oven at 100 C for 8 hours. Hydrocyanic acid was eliminated from dried cassava chips by using the dry-soak-dry method suggested by Rajaguru (1972/73). Cassava leaf meal was prepared from fresh cassava leaves, petioles and tender stems harvested at bimonthly intervals from plants maintained for leaf production. Leaves and petioles were wilted in the shade for three days and dried overnight in a unitherm oven at 100 Centigrade. The dried material was then ground into a semi-powdery form. Sweet potato leaf meal was prepared by grinding the oven-dried leaves and petioles, which were obtained from mature vines at the time of tuber harvest. The above meals were prepared in Sri Lanka. Sesame oil meal, coconut oil meal and rubber seed meal were purchased from a commercial source in Kandy, Sri Lanka.

Proximate Analysis. All analyses were done on air-dry samples. Dry matter, Kjeldahl nitrogen, ether extract and ash determinations

were performed by standard AOAC (1970) methods. Crude protein percent was calculated by multiplying nitrogen content by 6.25. Crude fiber determinations were made by the procedure of Whitehouse et al. (1945). Nitrogen-free extract was estimated by difference. Gross energy was determined with a Gallenkamp adiabatic bomb calorimeter.

Van Soest Fiber Analysis. The samples, ground through a 40 mesh screen, were analyzed for acid detergent fiber (ADF), permanganate lignin, cellulose, cutin, silica and ADF-nitrogen according to the procedures of Goering and Van Soest (1970). Neutral detergent fiber (NDF) was determined using the modified procedure described by Robertson and Van Soest (1977). Hemicellulose contents were calculated as the difference between ADF and NDF.

Mineral Analysis. For mineral analysis, samples were wet ashed using concentrated nitric and perchloric acids (Sandell, 1950). Mineral contents were determined on a Perkin-Elmer 403 Atomic Absorption Spectrophotometer. Phosphrous was determined by the colorimetric procedure of Fiske and Subbarow (1925).

Amino Acid Analysis. An automatic amino acid analyzer (Model TSM, Technicon Instruments, New York), equipped with a peak integrator was used to determine the amino acid composition. Samples were ground to pass a 60-mesh screen prior to analysis. Duplicate samples of each feedstuff were hydrolyzed in 6 N hydrochloric acid under nitrogen for 24 hours at 100 Centigrade. An aliquot of the hydrolyzed sample was dried over sodium hydroxide under vacuum. The samples were subsequently prepared for analysis by dissolving in .1 N hydrohloric acid.

RESULTS

Proximate and Cell Wall Composition. Proximate and Van Soest components of the feedstuffs are presented in Table 6. Cassava tuber meal was low in crude protein (2.9%) and ash (2.3%) contents but was rich in nitrogen-free extract (88.4%). Sesame oil meal had high crude protein (35.2%) and ash (23.7%) contents. Over 50% of this ash content, however, was found to be silica. The crude protein contents of coconut oil meal, rubber seed meal, cassava leaf meal and sweet potato leaf meal were 21.8, 12.0, 20.2 and 10.4%, respectively.

All the feedstuffs analyzed, except for cassava tuber meal, were high in ADF contents which ranged from 23.5% for sesame oil meal to 46.5% for sweet potato leaf meal. The high ADF content of rubber seed meal was primarily due to high content of cutin (22.0%).

Mineral Composition. Mineral contents of the feedstuffs are given in Table 7. Rubber seed meal and cassava tuber meal were found to be poor sources of most minerals. Sesame oil meal was rich in all minerals, especially calcium (2.32%), magnesium (.56%), iron (3236 ppm) and phosphorus (1.04%). Coconut oil meal contained high amounts of sodium (852 ppm) and potassium (1.83%), but was low in calcium (.07%). Cassava leaf meal was found to be a good source of minerals, except for copper (12 ppm), and was particularly rich in manganese (252 ppm) and zinc (249 ppm). Sweet potato leaf meal contained a moderate balance of all minerals. All the feedstuffs analyzed were low in copper, with coconut oil meal containing the highest copper content (46 ppm).

Amino Acid Composition. The amino acid composition of the feedstuffs are presented in Table 8. Tryptophan content of the feedstuffs

TABLE 6. PROXIMATE AND VAN SOEST COMPONENTS OF SOME TROPICAL FEEDSTUFFS

Constituent	Cassava Tuber Meal	Sesame Oil Meal	Coconut Oil Meal	Rubber Seed Meal	Cassava Leaf Meal	Sweet Potato Leaf Meal
Dry matter (DM) %	90.0	92.4	94.9	92.9	93.4	91.8
Proximate components, % of DM						
Crude protein	2.9	35.2	21.8	12.0	20.2	10.4
Crude fiber	5.0	23.1	21.5	34.7	29.0	36.9
Ether extract	1.4	7.0	9.4	11.1	6.2	3.3
Ash	2.3	23.7	6.5	2.3	7.8	12.2
Nitrogen-free extractives	88.4	11.0	40.8	39.9	36.8	37.2
Gross energy (kcal/g)	4.1	3.8	4.7	4.8	4.8	4.1
Van Soest components, % of DM						
NDF	15.1	34.8	53.4	68.0	48.8	51.6
ADF	5.0	23.5	29.4	39.1	35.0	46.4
Hemi-cellulose	10.1	11.3	24.0	28.9	13.8	5.2
Cellulose	3.1	15.9	23.8	6.1	23.6	32.2
Lignin	1.8	3.1	5.2	10.3	10.4	13.9
Cutin	-	5.7	-	22.0	-	-
Silica	-	12.2	-	-	-	-
ADF-N	.05	.16	.13	.15	.45	.63

TABLE 7. MINERAL CONTENTS OF SOME TROPICAL FEEDSTUFFS (DRY BASIS)

Mineral	Cassava Tuber Meal	Sesame Oil Meal	Coconut Oil Meal	Rubber Seed Meal	Cassava Leaf Meal	Sweet Potato Leaf Meal
Calcium, %	.09	2.32	.07	.10	1.35	.98
Magnesium, %	.08	.56	.30	.17	.42	.50
Iron, ppm	483	3236	768	623	859	976
Copper, ppm	6	35	46	24	12	17
Manganese, ppm	10	89	78	24	252	51
Zinc, ppm	41	171	149	60	249	66
Sodium, ppm	213	457	852	139	177	415
Potassium, %	.72	.79	1.83	.58	1.23	1.70
Phosphorus, %	.13	1.04	.63	.31	.45	.59

TABLE 8. AMINO ACID COMPOSITION (g/100 g DRY MATTER) OF SOME TROPICAL FEEDSTUFFS

Amino Acid	Cassava Tuber Meal	Sesame Oil Meal	Coconut Oil Meal	Rubber Seed Meal	Cassava Leaf Meal	Sweet Potato Leaf Meal
Aspartic acid	.12(4.17)[a]	2.35(6.62)	1.53(7.01)	1.12(9.33)	1.62(8.03)	1.03(9.93)
Threonine	.06(2.08)	1.07(3.04)	.61(2.80)	.34(2.83)	.71(3.52)	.44(4.24)
Serine	.06(2.08)	1.24(3.52)	.76(3.48)	.44(3.67)	.72(3.57)	.39(3.76)
Glutamic acid	.38(13.22)	5.80(16.48)	3.67(16.82)	1.63(13.58)	2.08(10.30)	.96(9.25)
Proline	.05(1.74)	.90(2.56)	.59(2.71)	.59(4.92)	.82(4.06)	.37(3.57)
Glycine	.20(6.96)	4.32(12.28)	2.41(11.05)	1.20(10.00)	2.61(12.96)	1.46(14.07)
Alanine	.09(3.13)	1.21(3.44)	.80(3.67)	.46(3.83)	.60(2.97)	.51(4.92)
Valine	.08(2.78)	1.83(5.20)	1.24(5.69)	.60(5.00)	1.07(5.30)	.54(5.21)
Cysteine	---	---	---	.12(1.00)	---	.07(.68)
Methionine	.02(.70)	.80(2.27)	.39(1.79)	.06(.42)	.26(1.29)	.10(.98)
Isoleucine	.06(2.08)	1.19(3.38)	.73(3.35)	.35(2.92)	.82(4.06)	.44(4.24)
Tyrosine	.10(3.48)	2.14(6.08)	1.39(6.37)	.74(6.17)	1.50(7.43)	.71(6.84)
Phenylalanine	.05(1.74)	1.40(3.98)	.93(4.26)	.41(3.42)	.97(4.81)	.51(4.92)
Lysine	.06(2.08)	.46(1.31)	.46(2.11)	.28(2.33)	.77(3.81)	.30(3.18)
Histidine	.01(.35)	.45(1.28)	.26(1.19)	.13(1.08)	.17(.84)	.11(1.06)
Arginine	.26(9.04)	4.11(11.68)	2.80(12.84)	.86(7.17)	.93(4.61)	.34(3.28)
Leucine	.10(3.48)	2.14(6.08)	1.39(6.37)	.74(6.17)	1.50(7.43)	.71(6.84)
Total amino acids	1.70(58.62)	31.41(89.23)	19.96(91.56)	10.07(83.92)	17.15(84.90)	8.99(86.44)

[a]Values in the parenthesis represent the amino acid profile of the feedstuffs, expressed as g/16 g N.

was not estimated, since it is destroyed by acid hydrolysis (Blackburn, 1968). The cysteine content of some of the feedstuffs was also not estimated, which again may be due to the same reason. It has been reported that cysteine may be destroyed during acid hydrolysis when carbohydrates are present but not in their absence (Block and Bolling, 1947).

In general, the feedstuffs analyzed contained low levels of methionine and lysine, except sesame oil meal and cassava leaf meal which had relatively high contents of methionine (.80%) and lysine (.77%), respectively. Glutamic acid followed by glycine, arginine and aspartic acid were generally high in all the protein supplements.

Sesame oil meal contained high levels of most of the essential amino acids, whereas rubber seed meal was found to be extremely deficient in methionine. The amino acid composition of cassava leaf meal was found to be similar to that of coconut oil meal. Although the amino acid contents of sweet potato leaf meal were appreciably lower than that of cassava leaf meal, the amino acid profiles (expressed as g/16 gN) of both meals with few exceptions compared favorably.

DISCUSSION

The high nitrogen-free extract fraction in cassava tuber meal is indicative of its potential value as an energy source. Proximate composition was remarkably similar to that of cassava tuber meal from Brazil (Olson et al.,1969a), Congo (Vogt, 1966), Tanzania (Wyllie and Lekule, 1980), Nigeria (Fetuga and Oluyemi, 1976), Philippines (Gerpacio, 1979) and Thailand (Khajarern et al., 1979). However, crude fiber estimation

was considerably higher than the values reported by most of these workers. An explanation for this difference may be that cassava tuber meal in this study was prepared from unpeeled tubers, whereas, because of the high HCN content of the peels (Joachim and Panditteseker, 1944), the above workers probably used peeled tubers. The dry-soak-dry method was employed in the preparation of cassava tuber meal in the present study because it greatly reduces the HCN content (Rajaguru et al., 1978), thus, making it possible to include peels in the meal. Cassava tuber meal contained very low levels of amino acids and minerals which is in agreement with other reports (Olson et al.,1969a; Orok and Bowland, 1974a; Wyllie and Lekule, 1980).

Sesame oil meal in the present study contained a lower crude protein content than reported for samples from Nigeria (Oluyemi et al., 1976), Tanzania (Naik, 1969), Mexico (Villegas et al., 1968) and North America (N.A.S., 1971). This low value may be due to contamination with chopped paddy straw which is used during the milling of sesame seed to maximize oil extraction from the mechanical expeller (Rajaguru, 1977). The high crude fiber content lends support to this view. The unexpectedly high content of silica (12.2%) possibly indicates adulteration with sand and strongly suggests the need to enforce strict quality control measures in the marketing of livestock feedstuffs in Sri Lanka. The possible contribution of paddy straw, at least in part, to this high silica content also cannot be overlooked. The Ca content was similar to values reported by N.A.S. (1971) and Naik (1969), however, values in the present study for Mn, K and P were lower than those reported by N.A.S. (1971). The amino acid composition of sesame oil meal was

comparable to that reported for Mexican (Villegas et al., 1968) and Indian (Rao and Bose, 1970) samples, but values in the present study were lower than listed by N.A.S. (1971) for North American samples.

The proximate composition of coconut oil meal compared favorably with values reported for Philippinian (Creswell and Brooks, 1971a), Ghanian (Owusu-Domfeh et al., 1970), Nigerian (Oluyemi et al., 1976) and Indian (Rao and Bose, 1970) samples, except the crude fiber content which was almost twice the level reported in the other studies. In general, the mineral composition was in close agreement with that obtained by Creswell and Brooks (1971a) and Mee and Brooks (1973) for samples from Philippines. However, values for aspartic acid, threonine, serine, tyrosine and histidine were lower, and those of glycine, valine and methionine were higher than those reported by Owusu-Domfeh et al (1970) for Ghanian samples.

Wide variations in crude protein and crude fiber contents of rubber seed meal were observed between values in the present study and those reported by other workers (Oluyemi et al., 1976; Buvanendran and Siriwardene, 1970). The samples in the present study contained a relatively low level of crude protein and an exceptionally high level of crude fiber. Almost 50% of the crude fiber fraction was found to be due to cutin. This is due to the Sri Lankan practice of including rubber seed shells during the milling of rubber seeds to increase oil extraction in the mechanical expeller process. This situation presents another case for the urgent need for quality control of livestock feedstuffs in Sri Lanka. The Ca and P values are considerably lower than the values of Oluyemi et al. (1976) for some Nigerian samples. Orok and Bowland

(1974b) reported that rubber seed meal contained fair amounts of the essential amino acids. This is in close agreement to values reported by Lever Bros. Ltd., Ceylon (1969 - unpublished report) for some Sri Lankan samples. Similar observations were made in the present study, except that our samples were extremely deficient in methionine.

Cassava leaf meal had a lower crude protein and higher crude fiber content than reported by Rogers and Milner (1963) for Jamaician and Brazilian samples. The Ca, Mg and P content were much higher and the Na content was much lower than the values reported by Eggum (1970) for some samples from Nigeria. Cassava leaf protein is low in methionine but rich in lysine (Eggum, 1970; Rogers and Milner, 1963). Although a similar trend was observed in the present study, the amino acid concentrations were found to be considerably lower. This disagreement could be explained by the differences in the stage of maturity at the time of harvest of these materials. Probably immature leaves were used by the above workers, whereas samples in the present study were prepared from mature leaves and petioles obtained at bimonthly harvests. The high crude fiber fraction (29.0%) for samples in the present study compared with the value of 5.9% for samples reported above lends support to this explanation. Otul (1973) found that the amino acid concentration of cassava leaves, particularly that of methionine and lysine, decreases with maturity. It must be pointed out, however, that the amino acid composition of cassava leaf meal still compares favorably with that of coconut oil meal highlighting the potential role that it could play as a substitute for the expensive coconut oil meal in balancing local livestock diets.

Sweet potato leaf meal contained fair amounts of minerals and was particularly high in Fe, Na, K and P. The mineral content of our sample was higher than the values of Chen and Chen (1979) for some Taiwanese samples. Although it had only 10.4% protein, amino acid composition was comparable to that of cassava leaf meal. Since sweet potato leaf meal, a by-product of sweet potato production will likely be available at cheaper prices, it can be expected to play some role in alleviating the shortage of protein supplements in Sri Lanka.

Amino acid nitrogen accounted for 58.6, 89.2, 91.6, 83.9, 84.9 and 86.4% of the total nitrogen of cassava tuber meal, sesame oil meal, coconut oil meal, rubber seed meal, cassava leaf meal and sweet potato leaf meal proteins, respectively. The lower amino acid nitrogen content of cassava tuber protein corresponds with values in the literature. Cassava tuber protein has been reported to contain only 60% amino acid nitrogen (Anon, 1973), the remainder yet to be identified. Low amino acid recovery obtained with other proteins may be indicative of the presence of non-protein nitrogen. Incomplete liberation and/or destruction of amino acids during hydrolysis could also have contributed to these low values (Blackburn, 1968).

With the possible exception of sesame oil meal, the sulfur amino acids are likely to be the most limiting amino acids when these protein concentrates are fed to livestock. However, the low values observed might be, at least in part, due to the loss of cystine and methionine during acid hydrolysis (Block and Bolling, 1947). The relatively high values of lysine in cassava leaf meal underlines its potential use as a source of lysine.

Chapter IV

TRUE METABOLIZABLE ENERGY VALUES OF CASSAVA TUBER MEAL, CASSAVA LEAF MEAL AND SESAME OIL MEAL FOR POULTRY

INTRODUCTION

In the past, it had been customary to use the nitrogen-corrected metabolizable energy (ME_n) values of feedstuffs as an estimate of available energy for poultry. These values, however, do not take into consideration the metabolic fecal and endogenous urinary energy losses (Sibbald, 1975). A rapid bioassay for true metabolizable energy (TMS) determinations, which corrects for the above losses, has been developed by Sibbald (1976a). This correction not only removes variations arising from differences in feed intake (Sibbald, 1975), but also reduces much of the variability between species and strains of birds (Sibbald, 1976b; Shires et al., 1980). Since the development of the TME bioassay is relatively recent, published information on the TME values of tropical feedstuffs is almost non-existent. The study reported herein was conducted to determine the TME values of three tropical feedstuffs for poultry.

MATERIALS AND METHODS

Twenty-four adult Single Comb White Leghorn roosters, which had been previously fed ad libitum, were used in the assay. All birds were individually housed in wire cages with free access to water. At the commencement of the trial, all birds were individually weighed, randomly allotted to four groups of equal weights and fasted for 24 hours

to empty their digestive tracts of feed residues.

Six roosters in each of three groups were then force-fed with approximately 25 g of a feedstuff. Three tropical feedstuffs, namely cassava tuber meal, cassava leaf meal and sesame oil meal were assayed. Six roosters were fasted for another 48 hours and served as the negative controls. Since the feedstuffs were either in a powdery or semi-powdery form, force feeding was accomplished as a suspension in pre-determined amounts of water. Any material remaining from the suspension was dried and weighed. Excreta voided by each bird was collected quantitatively for two consecutive 24-hour periods and dried in an oven at 95° C for 18 hours. The dry samples were weighed, ground and assayed for gross energy using a Parr Adiabatic Bomb Calorimeter. Crude protein determinations were performed by standard AOAC (1970) methods.

Dry matter digestibility (DMD) values were calculated using the following formula,

$$\text{DMD (\%)} = \frac{\text{DM input} - (\text{DM excretion of fed birds} - \text{DM excretion of negative controls})}{\text{DM input}} \times 100$$

Crude protein digestibility values were calculated in a similar manner. TME values were calculated for each feedstuff as described by Sibbald (1976a).

$$\text{TME (kcal/g)} = \frac{\text{Energy input} - (\text{Energy excretion of fed birds} - \text{Energy excretion of negative controls})}{\text{Feed input}} \times 100$$

The data were subjected to statistical analysis using a student's "t" Test (Sokal and Rohlf, 1969).

RESULTS AND DISCUSSION

The DMD values of the feedstuffs are presented in Table 9. Increasing the excreta collection period from 24 to 48 hours did not result in any significant ($P<0.05$) differences in DMD values for cassava tuber meal and sesame oil meal. This would suggest that a 24-hour collection period was adequate for these feedstuffs. A significant ($P<0.01$) reduction in DMD values of cassava leaf meal was, however, observed when the collection was extended to 48 hours. The high variability observed with the DMD values of cassava leaf meal was due mainly to the high DMD values of two of the original six birds. Difficulty was experienced in force-feeding these two birds which might have caused crop impaction and incomplete elimination of feed residues at 48 hours. This would suggest that a collection period of 48 hours or longer was required for cassava leaf meal. A similar trend was observed for the TME values of the feedstuffs (Table 10).

The high nitrogen-free extract fraction (88.4%) along with its high DMD (93.7%) demonstrate the potential value of cassava tuber meal as an energy source in tropical livestock rations. The ME_n of cassava tuber meal has been reported to vary from 3.20 kcal/g (Aquirre *et al*, 1979) to

TABLE 9. DRY MATTER DIGESTIBILITY VALUES OF THREE TROPICAL FEEDSTUFFS

Feedstuff	Number of Observations	Dry Matter Intake in Grams (Mean + SD)	% DMD[a] (Mean ± SD)	
			24 Hr	48 Hr
Cassava tuber meal	6	21.68 ± .56	92.31 ± 1.38	93.72 ± 6.15
Cassava leaf meal	6	19.30 ± 4.45	47.29 ± 21.67	34.63 ± 13.26[b]
Sesame oil meal	6	22.07 ± 4.0	45.32 ± 1.36	46.99 ± 3.42

[a]Metabolic and endogenous dry matter losses during a 24-hour period, following 24 or 48 hours of starvation, were 3.36 ± .59 and 4.15 ± .60 g, respectively.

[b]Appendix Table 1.

TABLE 10. TRUE METABOLIZABLE ENERGY VALUES (IN KCAL/G) OF THREE TROPICAL FEEDSTUFFS

Feedstuff	No. of Observations	TME Values (Mean ± SD)[a,b] 24 Hr.	48 Hr
Cassava tuber meal	6	3.76 ± .06	3.76 ± .13
Cassava leaf meal	6	2.86 ± .70	1.99 ± .28
Sesame oil meal	6	2.42 ± .09	2.45 ± .14

[a]Metabolic and endogenous energy losses during a 24-hour period, following 24 or 48 hours of starvation, were 4.90 ± 1.18 and 5.83 ± .94 kcal/kg bodyweight, respectively. Roosters averaged 2.12 ± .27 kg at the commencement of the assay.

[b]Appendix Table 2.

TABLE 11. CRUDE PROTEIN DIGESTIBILITY VALUES OF THREE TROPICAL FEEDSTUFFS

Feedstuff	% Crude Protein Digestibility (Mean ± SD)[a]
Cassava tuber meal[b]	91.26 ± 3.09
Cassava leaf meal[c]	62.92 ± 7.12
Sesame oil meal[d]	68.75 ± 2.62

[a]Metabolic and endogenous crude protein losses during a 24-hour period following 24 or 48 hours of starvation were 4.03 ± .59 and 9.05 ± 1.20 g, respectively.

[b,c]Values based on 24 and 48 hour collection periods, respectively.

4.31 kcal/g (Maust et al., 1972b). Based on growth data, Vohra (1975) suggested that a mean value of 3.44 kcal/g may be preferred. Although the TME of cassava tuber meal is slightly lower than those reported for corn (Sibbald, 1977b; Halloran, 1980; Shires et al., 1980), it could still play an important role in replacing expensive corn in tropical livestock rations.

Only 45.3% of the dry matter of sesame oil meal was found to be truly digestible. This poor digestibility could be possibly attributed to the high contents of crude fiber (23.1%) and silica (12.2%) in our samples. However, sesame meal protein had a digestibility value of 68.8% (Table 11). The high silica content of our samples is probably due to adulteration with sand. The high fiber content may be attributed to the Sri Lankan practice of using chopped paddy straw during milling of sesame seed to maximize oil extraction from the mechanical expeller (Rajaguru, 1977). Gohl (1975) reported the ME_n of sesame oil meal containing 8% ether extract to be 2.98 kcal/g. The TME of our samples were determined to be 2.42 kcal/g. The low energy value of our samples may be again attributed to its high fiber and silica contents. Silica may adversely affect the ability of the birds to utilize energy (Muztar et al, 1977). However, Sibbald (1980a) force-fed different grains with various amounts of finely ground silica sand and found that sand had no effect on TME values of the grains.

Although the amino acid composition of cassava leaf meal compares favorably with that of coconut oil meal (Table 8), which is the commonly used protein supplement in many tropical countries, its low DMD (34.6%) may limit its potential use in poultry rations. However, 62.9%

of cassava leaf protein was found to be truly digestible (Table 11). Studies on amino acid availabilities of cassava leaf meal are essential to further evaluate its potential as a source of protein for poultry. No published information is available on the ME_n value of cassava leaf meal for poultry. However, the TME value of our cassava leaf meal samples is higher than that reported for dehydrated alfalfa meal containing 21% crude protein (Sibbald, 1977b).

Chapter V

EFFECTS OF CRUDE FIBER AND VIRGINIAMYCIN ON THE DIGESTA RATE OF PASSAGE AND NUTRITIONAL PARAMETERS IN GROWING SWINE

INTRODUCTION

It is now widely recognized that fibrous feedstuffs will play an important role in swine production in the future, as competition for traditional low fiber feedstuffs becomes greater. Although the use of fibrous feedstuffs in swine diets is physiologically plausible (Rerat, 1978) and economically advantageous, the depressing effects of high levels of fiber on the digestion of other nutrients (Cunningham et al., 1962; Pond et al., 1962; Bowland et al., 1970; Keys and DeBarthe, 1974; Campabadal et al., 1976; Kornegay, 1978; Kass et al.,1980a) present grounds for concern. The mechanism(s) by which high levels of fiber affects the apparent digestibility of other dietary constituents is not clearly understood at the present time. One possible mechanism of action is through its effect in increasing the rate of passage of digesta (Kass et al.,1980a). With a faster rate of passage, there would be less opportunity for both enzymatic and microbial digestion in the digestive tract.

Public concern regarding the potential hazards of continuous feeding of subtherapeutic level of antibiotics which are important in human and veterinary medicine has stimulated interest in the dietary use of those antibiotics which are not used for disease control. Virginiamycin, an antibiotic developed solely for use in animal feeding, has been recently shown to slow the rate of passage of digesta in swine

(Fausch, 1981). This finding looks promising, at least to some extent, for counteracting the faster rate of passage of fibrous ingredients and thus improving nutrient utilization in diets based on fibrous feedstuffs.

The present study was conducted to evaluate the influence of crude fiber level and Virginiamycin on the rate of passage of digesta and nutrient digestibility of growing swine.

MATERIALS AND METHODS

DIGESTION TRIALS

Three metabolism trials, each involving twelve crossbred gilts averaging 35 kg body weight, were conducted to study the effects of two levels (3.2 and 7.3%) of crude fiber and two levels (0 and 11 ppm) of Virginiamycin on nutritional parameters. A 2 x 2 factorial arrangement was used in each trial.

Two basal diets were formulated as shown in Table 12. Both diets were isonitrogenous and isocaloric. Low fiber diet was based on corn as the cereal source. The high fiber diet was formulated using 50% medium ground oats and the resultant dilution in metabolizable energy was balanced by the addition of 6% corn oil. Each of the two basal diets was fed with and without supplementation of 11 ppm Virginiamycin.[1]

Pigs were randomly assigned to each of the four dietary treatments from outcome groups based on body weight. Animals were individually housed in stainless steel metabolism cages in an environmentally

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[1]Smith Kline Animal Health Products, Philadelphia

controlled room (24° C), and allowed seven to ten days to adapt to the cages. Experimental diets were mixed with equal amounts of water and gilts were fed 4% of their body weight in two equal feedings during an 8-day adjustment period which preceded a 5-day collection period. Sufficient drinking water was provided in the troughs after each meal.

Urine was filtered through glass wool into nalgene bottles containing 25% v/v sulfuric acid to maintain the pH below 5.5. Urine collections were pooled daily and volume was measured on day 5. Aliquots were taken for analyses and frozen. Total fecal collections were made daily, weighed and dried in a forced air oven at 60° C for 36 hours. After drying, the samples were allowed to attain equilibrium with atmospheric moisture, reweighed and stored in airtight plastic bags. At the end of the collection period, the dried feces were pooled and ground in a Wiley mill equipped with a 40-mesh screen before representative samples were taken.

A Parr oxygen bomb calorimeter was used to determine the gross energy of feed and feces. Samples of approximately 250 ml of urine were lyophilized, and the dry matter of the urine was calculated. Gross energy of the lyophilized urine was determined in the bomb calorimeter using 1 g dried urine with .5 ml of ethanol added to each sample to facilitate ignition. The correction factor for urinary nitrogen was calculated from the data to be 14.27 kcal per gram of urinary nitrogen excreted. Ash determination on feed and fecal samples and Kjeldahl nitrogen of feed, fecal and urine samples were made by the standard AOAC (1970) procedures. Cell wall, cell contents, acid detergent fiber, cellulose, hemicellulose and lignin were analyzed according to the procedures

TABLE 12. PERCENTAGE COMPOSITION OF DIETS FOR DIGESTION AND RATE OF PASSAGE TRIALS

Ingredient	Low Fiber	High Fiber
Ground corn (IFN 4-02-931)	79.28	25.60
Ground oats (IFN 4-03-388)	-	50.00
Soybean meal (IFN 5-04-612)	18.62	16.20
Corn oil (IFN 4-07-882)	-	6.00
Deflourinated phosphate (IFN 6-01-780)	.90	1.07
Limestone (IFN 6-02-632)	.64	.57
Salt	.30	.30
Vitamin-Se Premix[a]	.20	.20
Trace mineral premix[b]	.06	.06
Calculated analysis		
Crude protein, %	16.00	16.10
Crude fiber, %	3.20	7.30
Metabolizable energy, kcal/kg	3285	3284

[a]Supplied (per kilogram of premix): 1.32 g riboflavin, 6.8 g pantothenic acid, 6.8 g niacin, 10.6 mg vitamin B_{12}, 220 g choline chloride, 13,200,000 IU vitamin A, 220,000 IU vitamin D, 2,200 IU vitamin E, 330 mg MPB (vit. K) and 40 mg Se.

[b]Contained (%): Co .01, Cu .10, Fe .50, 1.01, Mn .80, Zn 1.0, sulfur .24, NcCl (balance).

of Goering and Van Soest (1970).

After the completion of the first total collection digestion trial, .5% chromic oxide was included in the experimental diets and fed for five days to equalize the chromic oxide content of the feces (Clawson et al., 1955). "Grab" samples of feces were taken on day 5 and pooled. This enabled a direct comparison between the conventional total collection method and the indicator method for determining nutrient digestibility. Chromic oxide analyses of the feed and feces were made by a modification of the method outlined by Hill and Anderson (1958). Nutrient digestibility was calculated by the ratio of the concentration of chromic oxide to that of a given nutrient in the feed and the same ratio in the feces resulting from the feed (Maynard and Loosli, 1969).

RATE OF PASSAGE TRIALS

Rate of passage of digesta through the digestive tract was determined in five separate studies involving three groups of twelve crossbred gilts each. Three determinations of passage rate were made with one group of pigs, while the other two groups were used for one determination each. Pigs, weighing an average of 34.6 kg, were maintained individually in metabolism cages in an environmentally controlled room (24° C). Experimental diets (same as in digestion trials) were fed in gruel-form for at least seven days before the observations began. Pigs were fed 4% of body weight each day in two equal feedings.

Passage rate was measured by adding .5% chromic oxide to the diets in the morning and visually observing the time taken for the first appearance of marker in the feces. The pigs were checked every 15

minutes for fecal excretion and for first appearance of the marker.

Data from both digestion trials and rate of passage trials were analyzed according to the analysis of variance procedures of the statistical Analysis System (Barr and Goodnight, 1972).

RESULTS AND DISCUSSION

DIGESTION TRIALS

Daily gain and feed efficiency were similar for gilts fed high and low levels of fiber (Table 13). This is in agreement with the findings of Baird et al (1975), who reported that pigs can sustain growth performance with high levels of fiber when the energy density of the diet is adequate. Although a trend towards improvement was observed when the high fiber diet was supplemented with Virginiamycin, the differences were not statistically significant (Table 13). Data on the performance traits, however, should not be considered conclusive because of the short duration of digestion trials.

Fecal dry matter output increased ($P<.001$) as the level of fiber was increased in the diet (Table 13), which is in accord with reports by Kornegay (1978, 1981). On the other hand, Virginiamycin supplementation decreased ($P<.05$) fecal dry matter output of both low and high fiber diets. Fecal dry matter values did not differ between pigs fed different dietary treatments, although a four percentage unit increase was observed for pigs fed the high fiber diet without Virginiamycin. However, others (Henry, 1976; Kornegay, 1978 and 1981; Kass et al., 1980a) have reported a decrease in fecal dry matter percentage with increasing levels of fiber. Fiber level had no effect on urine volume. In agreement,

TABLE 13. AMOUNT OF FEED, FECES AND URINE, FECAL DRY MATTER, AVERAGE DAILY GAIN AND FEED PER GAIN OF GILTS IN THE DIGESTION TRIALS

Virginiamycin	Low Fiber		High Fiber	
	-	+	-	+
No. of pigs	9	9	9	9
Avg. initial wt., kg	35.88	34.62	34.76	35.43
Avg. final wt., kg	41.09	39.97	39.57	40.63
Avg. daily gain, kg	.37	.38	.34	.37
Dry matter intake, kg/day	1.22	1.22	1.22	1.23
Dry matter per gain	3.30	3.21	3.59	3.32
Fecal dry matter output, g/day[a,b]	143.00	139.30	267.40	243.80
Dry matter of fresh feces, %	34.96	33.79	38.29	34.61
Urine volume, l/day	2.32	2.62	2.39	2.56

[a]Fiber effects ($P<.001$).

[b]Virginiamycin effects ($P<.05$).

Kornegay (1981) found no difference in urine volume between gilts fed different levels of soybean hull, but others (Henry, 1976; Kornegay, 1978) have reported a decrease in urine volume as the level of fiber was increased. Virginiamycin supplementation did not significantly affect urine volume, but values tended to increase with supplementation.

Effects of fiber and Virginiamycin on digestion coefficients and nitrogen balance are shown in Table 14. Increasing the level of fiber depressed the digestibility of dry matter ($P<.001$), energy ($P<.001$), crude protein ($P<.10$) and ash ($P<.001$), which is in accord with other reports (Cunningham et al., 1962; Pond et al, 1962; Bowland et al., 1970; Keys and DeBarthe, 1974; Campabadal et al., 1976; Kornegay, 1978; Kass et al., 1980a). The effects of fiber on the digestibility of fibrous components has been varied. The lower ($P<.001$) digestibility of cell contents, cell wall, acid detergent fiber, hemicellulose, cellulose and lignin with the increased level of fiber in the diet is in consensus with those reported by Pollmann et al. (1979). However, Kornegay (1978, 1981) observed increase in the digestion coefficients for acid detergent fiber, cellulose and lignin as soybean hulls were substituted for a corn-soybean meal basal diet. The digestion of cell wall and hemicellulose was not affected. Keys et al. (1970) reported that increasing the dietary cell wall content had no effect on the digestibility of cell wall and cellulose, but depressed the hemicellulose digestion. The variation that exists in the chemical composition of cell walls of fibrous feedstuffs may be the major factor contributing to these variable results.

Increased fecal nitrogen excretion with increasing levels of fiber has been shown by several workers (Meyer, 1956; Whiting and Bezeau, 1957; Fahey et al., 1980). Farrell (1973) and Mason et al. (1976) attributed this increase in fecal nitrogen to an increase in the nitrogen of microbial origin, a result of increased bacterial activity on high fiber diets. Our findings are in agreement with these results, but disagrees with those of Kass et al. (1980a) and Sherry et al (1981) who found no effect of fiber level on fecal nitrogen. Although the nitrogen digestibility was depressed ($P<.10$), because of a non-significant decrease in urinary nitrogen excretion, nitrogen retention as a percent of digested nitrogen was increased ($P<.10$) for the high fiber diets. Similar effects of fiber on nitrogen retention have been reported by Likuski et al (1961), Kornegay (1978), Corley et al. (1978) and Sherry et al. (1981). Conversely, Fahey et al. (1980) found no significant effect on nitrogen retention by the addition of 10% solka floc, alphacel or hydrolyzed alphacel to a semi-purified diet. It appears that level and source of fiber and type of diet influence nitrogen retention (Sherry et al., 1981).

The possibility that high fiber diets could lead to mineral deficiencies has long been known (McCance and Widdowson, 1942). Although data with regard to swine are limited, research on other non-ruminant species clearly indicate that fiber may have adverse effects on the availability of calcium, phosphorus, zinc, iron, magnesium (Spiller and Shipley, 1977), copper and manganese (Davies and Nightingale, 1975). The lowered ($P<.001$) digestion coefficients for ash with high fiber diets in our study appears to be suggestive of this possibility. Further

investigations are needed to study this potentially important interrelationship in swine diets.

Digestion coefficients for dry matter ($P<.01$), energy ($P<.01$), metabolizable energy ($P<.10$), crude protein ($P<.10$) and ash ($P<.10$) were increased by the supplementation of Virginiamycin (Table 14). Although Virginiamycin supplementation increased the cell wall digestibility, the differences were not significant. Virginiamycin supplementation had no effect on the digestibility of any of the cell wall components. Our results are in agreement with those of Gorril et al. (1960), who found an improvement in energy digestibility following the supplementation of a mixture of penicillin, streptomycin and aureomycin. However, Sherry et al. (1981) reported that Aureo-SP 250 supplementation had no effect on the digestibility of cellulose or energy in growing swine. Conversely, Forbes and Hamilton (1952) observed that inclusion of sulfathalidine resulted in significant reductions in crude fiber and cellulose digestibility in swine. Gargallo and Zimmerman (1981) infused neomycin into the cecum and noted a complete cessation of cellulose digestion. Thus, source of antibiotic appears to influence the effect of antibiotic on colonic microorganisms and cell wall component digestion. It is possible that Virginiamycin, being an antibiotic developed solely for use as a feed additive, does not inhibit cell wall-splitting colonic microorganisms or creates a favorable environment for their multiplication, thereby improving the energy utilization.

Fecal nitrogen excretion was decreased ($P<.05$) by Virginiamycin supplementation (Table 14). Mason et al. (1976) attributed this reduction to a decrease in the proportion of nitrogen of microbial origin

in the total fecal nitrogen. However, because of a non-significant increase in urinary nitrogen excretion, nitrogen retention (both as a percent of intake and digested nitrogen) was depressed ($P<.10$) with Virginiamycin supplementation. To the contrary, Sherry et al. (1981) reported that addition of Aureo-SP 250 depressed the urinary nitrogen excretion. They attributed this depression, in part, to changes in microbial metabolic activities. Our data are insufficient to explain the reduction in nitrogen balance due to Virginiamycin supplementation, especially since the average daily gain of pigs was not affected by the treatments (Table 13).

Fiber x Virginiamycin interactions were observed ($P<.10$) for dry matter, energy, metabolizable energy (corrected) and cell wall digestion coefficients (Table 15), indicating that Virginiamycin is beneficial in improving the energy utilization when supplemented to a high fiber diet than to a low fiber diet. Non-significant ($P<.15$) interactions toward improvements in the digestibilities of acid detergent fiber, hemicellulose and cellulose were also seen.

RATE OF PASSAGE STUDIES

Rate of passage of digesta through the digestive tract, as measured by the appearance of chromic oxide in the feces, was faster ($P<.01$) with the high fiber diet (Table 14). This faster rate of passage was associated with depressions in the digestion of dry matter and other dietary constituents (Table 14). This relationship appears to be due to the decrease in time available for microbial and enzymatic digestion. Kass et al. (1980a) also related faster passage rate to less efficient diges-

TABLE 14. MAIN EFFECTS ON PASSAGE RATE, NUTRIENT DIGESTIBILITY AND NITROGEN BALANCE IN GROWING SWINE

Parameter	Fiber Effects			Virginiamycin Effects		
	Low Fiber	High Fiber	Trt. Sig.[a]	0 ppm	11 ppm	Trt. Sig.[a]
Rate of passage, hr[b]	26.4	20.9	**	20.6	26.7	**
Digestibility,%[c]						
Dry matter	88.4	79.1	***	83.2	84.3	**
Digestible energy	87.2	79.7	***	82.9	84.0	**
Metabolizable energy	84.8	77.6	***	80.7	81.6	†
Metabolizable energy corr.[d]	79.6	71.9	***	74.8	76.7	†
Cell content	92.5	90.2	***	91.0	91.7	NS
Cell wall	68.1	44.7	***	54.5	58.3	NS
Acid detergent fiber	59.2	24.2	***	41.1	42.3	NS
Hemicellulose	70.7	54.2	***	62.3	62.6	NS
Cellulose	51.8	22.7	***	36.9	37.6	NS
Lignin	74.8	39.5	***	57.5	56.9	NS
Crude protein (N x 6.25)	86.9	85.9	†	85.9	86.9	†
Ash	64.1	52.6	***	55.5	61.2	†
Nitrogen Balance[c]						
Intake, g/day	35.1	35.7	NS	35.6	35.3	NS
Fecal excretion, g/day	4.6	5.0	*	5.0	4.6	*
Urinary excretion, g/day	10.0	8.8	NS	8.7	10.1	NS
Nitrogen retention, g/day	20.5	21.9	†	21.9	20.6	†
Nitrogen retention[e]	58.4	61.1	NS	61.5	58.4	†
Nitrogen retention[f]	67.2	71.3	†	71.6	67.1	†

[a]Probability of treatment effects, † P<.10, * P<.05, ** P<.01, *** P<.001.
[b]Each value represents a mean of 30 observations.
[c]Each value represents a mean of 18 pigs.
[d]Corrected for urinary nitrogen.
[e]Percent of intake.
[f]Percent of digested.

TABLE 15. EFFECTS OF FIBER X VIRGINIAMYCIN INTERACTION ON PASSAGE RATE, NUTRIENT DIGESTIBILITY AND NITROGEN BALANCE IN GROWING SWINE

	Low Fiber		High Fiber	
Virginiamycin, ppm	0	11	0	11
Rate of passage, hr[a]	23.1	29.6	18.0	23.9
Digestibility, %[b]				
Dry matter[c]	88.2	88.6	78.1	80.1
Energy[c]	87.0	87.5	78.8	80.6
Metabolizable energy	84.7	84.8	76.7	78.4
Metabolizable energy corr.[c,d]	79.0	80.2	70.6	73.1
Cell content	92.2	92.8	89.7	90.7
Cell wall[c]	69.0	67.1	39.9	49.5
Acid detergent fiber	60.2	58.2	22.0	26.4
Hemicellulose	71.7	69.8	52.9	55.4
Cellulose	53.1	50.4	20.6	24.9
Lignin	75.8	73.9	39.2	39.9
Crude protein (N x 6.25)	86.4	87.4	85.5	86.5
Ash	62.8	65.3	48.2	57.1
Nitrogen balance[b]				
Intake, g/day	35.3	34.9	35.8	35.7
Fecal excretion, g/day	4.8	4.4	5.2	4.8
Urinary excretion, g/day	9.0	11.0	8.4	9.2
Nitrogen retention, g/day	21.5	19.5	22.2	21.6
Nitrogen retention[e]	60.9	55.9	62.0	60.8
Nitrogen retention[f]	70.5	63.9	72.6	70.2

[a]Each value represents a mean of 15 observations.
[b]Each value represents a mean of 9 pigs.
[c]Probability of interaction effects, P<.10.
[d]Corrected for urinary nitrogen.
[e]Percent of intake.
[f]Percent of digested.

tion in swine. The faster rate of passage of high fiber diets is attributed primarily to the mechanical stimulus of distention due to the presence of bulky residues in the colon (Monte, 1981).

Supplementation with Virginiamycin prolonged ($P<.01$) the passage rate of digesta from 20.6 to 26.7 hr (Table 14), confirming the findings of Fausch (1981). This slower passage rate was associated with improved digestion coefficients for dry matter, energy, metabolizable energy, crude protein and ash (Table 14), further highlighting the crucial relationship that appears to exist between passage rate and digestion.

No fiber x Virginiamycin interaction was observed with regard to the rate of passage (Table 15). Virginiamycin slowed the passage rate of digesta of both low and high fiber diets, but improved digestibility only in the high fiber diet (Table 15). If large intestine is the primary organ regulating the passage rate of digesta and dietary fiber (Clemens et al., 1975; Kass et al., 1980a), our data appears to suggest that Virginiamycin prolongs the retention of digesta in the large intestine, thereby exposing the digesta high in cell wall content to microbial digestion for a long time. The improved energy digestibility may also be indicative of the fact that products of cell wall degradation are utilized for energy by the swine.

CONVENTIONAL VS INDICATOR METHOD

The digestibility values obtained by the indicator method for dry matter ($P<.001$), crude protein ($P<.05$), energy ($P<.001$), cell content ($P<.001$), cell wall ($P<.01$), hemicellulose ($P<.001$) and ash ($P<.10$) were

lower than those obtained by the conventional method for the high fiber diet (Table 16). However, no significant differences were seen between the digestion coefficients estimated by conventional and indicator methods for the low fiber diet (Table 16) or for the diets fed with or without Virginiamycin (Table 17). Our data suggest that the indicator method can be used to estimate nutrient digestibility values of low fiber diets with reasonable accuracy but with diets high in fiber it may result in underestimation. Clawson et al. (1955) also reported that for feeds that are well digested the indicator method yields values comparable to conventional method. But with diets that are poorly digested, a chromic oxide recovery of less than 90% could result in appreciable error. Although the rate of chromic oxide recovery was not determined in the present study, it is possible that the faster rate of passage of high fiber diet may have lowered chromic oxide recovery.

The treatment effects on nutrient digestibility were similar for both methods, with a few exceptions. Results from the indicator method showed a reduction ($P<.01$) in the digestion coefficient for ash when the fiber level was increased, whereas results from the conventional method did not show any significant difference (Table 16). The digestion coefficients for dry matter and cell content from conventional method showed improvements ($P<.05$) due to Virginiamycin supplementation (Table 17). However, the corresponding values from the indicator method were not significant.

The results reported herein suggest that Virginiamycin supplementation to a high fiber diet is more beneficial than to a low fiber diet. Virginiamycin slows the rate of passage of digesta and improves nutrient

utilization, evidently through its influence on colonic micro-organisms that favor cell wall degradation. Further studies on the microbiology of colon are needed before mechanism(s) by which Virginiamycin alters the passage rate and fiber digestion can be clearly elucidated.

TABLE 16. COMPARISON OF PERCENTAGE NUTRIENT DIGESTIBILITY VALUES[a] AS DETERMINED BY CONVENTIONAL TOTAL COLLECTION AND INDICATOR METHODS, MAIN EFFECTS OF FIBER LEVEL

Nutrient	Low Fiber[b]		High Fiber[c]	
	Conventional	Indicator	Conventional	Indicator
Dry matter	87.6[d]	89.1[d]	77.0***	72.2
Crude protein	87.1[e]	87.4[d]	85.4*	82.7
Energy	86.6[d]	88.3[d]	77.8***	73.6
Cell content	92.0[f]	93.6[d]	89.5***	86.6
Cell wall	68.8[d]	68.7[d]	37.8**	32.1
Acid detergent fiber	59.8[d]	59.9[d]	18.2	19.0
Hemicellulose	71.7[d]	72.4[d]	51.5***	42.2
Cellulose	53.2[d]	56.2[d]	18.4	18.4
Lignin	74.7[d]	72.4[f]	32.9	30.0
Ash	55.4	57.1[f]	57.1†	49.8

[a]Each value represents a mean of 6 pigs.
[b]Differences in digestibility values between conventional and indicator methods were not statistically significant.
[c]Probability of method effect within high fiber level, † P<.10, * P<.05, ** P<.01, *** P<.001.
[d]Fiber effect within each method (P<.001).
[e]Fiber effect within each method (P<.05).
[f]Fiber effect within each method (P<.01).

TABLE 17. COMPARISON OF PERCENTAGE DIGESTIBILITY VALUES[a] AS DETERMINED BY CONVENTIONAL TOTAL COLLECTION AND INDICATOR METHODS, MAIN EFFECTS OF VIRGINIAMYCIN

Nutrient	No Virginiamycin[b]		11 ppm Virginiamycin[b]	
	Conventional	Indicator	Conventional	Indicator
Dry matter	81.6[d]	80.3	83.1	81.1
Crude protein	85.9	84.9[c]	86.6	85.2
Energy	81.5[c]	80.4[d]	82.9	81.5
Cell content	90.1[e]	89.7[d]	91.5	90.5
Cell wall	51.6[d]	49.6	55.1	51.2
Acid detergent fiber	37.8	39.3	40.1	39.7
Hemicellulose	61.0	56.7	62.2	57.9
Cellulose	34.2	36.5	37.4	38.0
Lignin	53.8	51.0[d]	53.8	51.4
Ash	52.1[d]	50.9[d]	60.4	55.4

[a]Each value represents a mean of 6 pigs.
[b]Differences in digestibility values between conventional and indicator methods were not statistically significant.
[c]Virginiamycin effect within method ($P<.01$).
[d]Virginiamycin effect within method ($P<.05$).
[e]Virginiamycin effect within method ($P<.10$).

LITERATURE CITED

Ademosun, A. A. and N. O. Eshiett. 1980. Feeding cassava root meal to starter, grower and laying chickens. Trop. Agr. (Trinidad). 57:277.

Agudu, E. W. 1972. Preliminary investigations on some unusual feedstuffs in yolk pigmenters in Ghana. Ghana J. Agr. Sci. 5:33.

Ahmed, I. M. 1973. Potential fodder and tuber yields of two varieties of tapioca. Malaysian Agr. J. 49:166.

Allee, E. L. 1977. Using dehydrated alfalfa to control intake of self-fed sows during gestation. Feedstuffs. (USA). 49(16):20.

Almquist, H. J. and C. R. Grau. 1944. Mutual supplementary effect of the proteins of soybean and sesame meal. Poul. Sci. 23:341.

Anon. 1903. The commercial utilization of the seeds of the para rubber tree. Bull. Imp. Institute. 1:156.

Anon. 1973. Swine production systems. CIAT. Cali. Colombia. pp. 121.

A.O.A.C. 1970. Official methods of analysis. (11th Ed.). Association of Official Analytical Chemists. Washington, D.C.

Aguirre, M., A. Shimada and E. Avila. 1979. Metabolizable and net energy values of cassava meal for chicks. Poul. Sci. 58:694.

Arambawela, W. J., H. E. Nielsen, V. Danielsen and B. O. Eggum. 1975. Effect of replacing barley with tapioca meal at two different levels of feeding on the growth and health of early weaned pigs. Livestock Prod. Sci. 2:281.

Argenzio, R. A. and M. Southworth. 1975. Sites of organic acid production and absorption in gastrointestinal tract of the pig. Amer. J. Physiol. 228:454.

Aumaitre, A. 1969. Nutritive value of manioc and different cereals in early weaning diets for the piglet: digestive utilization of feed and its effects on growth of the animal. Ann. Zootechnie. 18:385.

Baird, D. M., H. C. McCampbell and J. R. Allison. 1970. Level of crude fiber with constant energy levels of growing-finishing swine using computerized rations. J. Anim. Sci. 31:518.

Baird, D. M., H. C. McCampbell and J. R. Allison. 1975. Effect of levels of crude fiber, protein and bulk in diets for finishing hogs. J. Anim. Sci. 41:1039.

Baker, D. H., B. G. Harmon and A. H. Jensen. 1974. Value of alfalfa meal and wheat bran in diets for swine during prefarrowing and lactation. J. Anim. Sci. 39:838.

Barr, J. A. and J. H. Goodnight. 1972. A user's guide to the statistical analysis system. North Carolina State University. Raleigh.

Blackburn, S. 1968. Amino Acid Determination - Methods and Techniques. Mercel Decker, Inc. New York.

Block, R. J. and D. Bolling. 1947. The Amino Acid Composition of proteins and foods. 1st Ed. C. C. Thomas. Springfield, Illinois.

Bohman, R., J. E. Hunter and J. McCormick. 1955. The effect of graded levels of alfalfa and aureomycin upon growing-finishing swine. J. Anim. Sci. 14:499.

Bowland, J. P. H. Bickell, H. P. Pfirter, C. P. Wenk and A. Schurch. 1970. Respiration calorimetry studies with growing pigs fed diets containing from three to twelve percent crude fiber. J. Anim. Sci. 31:494.

Boyd, R. D., T. D. Creshaw, B. D. Moser, E. R. Peo, Jr. and D. M. Danielson. 1976. Nutritional value of energy and N content of sun-dried alfalfa for gilts and sows. J. Anim. Sci. 42:1348. (Abstr.).

Bredemen, C. 1931. Does the HCN content of rubber seed adversely affect the use of rubber seed cake as an animal feed? Der Tropen Pflander. 34:249.

Brown, P. B., D. E. Becker, L. E. Card and S. W. Terrill. 1951. The effect of aureomycin on rate of gain and efficiency of feed utilization by growing-finishing swine. J. Anim. Sci. 10:1042.

Butterworth, M. H. and H. C. Fox. 1963. The effect of heat treatment on the nutritive value of coconut oil meal and the prediction of nutritive value by chemical methods. Brit. J. Nutr. 17:445.

Buvanendran, V. and J. A. De S. Siriwardene. 1970. Rubber seed meal in poultry diets. Ceylon Vet. J. 18(2):33.

Buvanendran, V. 1971. Effect of rubber seed meal on hatchability of hens' eggs. Trop. Agriculturist 127:111.

Campabadal. C., C. Cresswell, H. D. Wallace and G. E. Combs. 1976. Nutritional value of rice bran for pigs. Trop. Agr. (Trinidad). 53:141.

Cheeke, P. R. 1977. Progress in development of alfalfa as a feedstuff for nonruminants. Feedstuffs (USA). 49(23):48.

Chen, M. C. and C. P. Chen. 1979. Chemical composition and nutrient digestibility of agricultural by-products in Taiwan. J. Agr. Assoc. China. 106:62.

Chew, M. Y. 1972. Cyanide content of tapioca leaf. Malaysian Agr. J. 48:354.

Chicco, C. F., S. T. Garbati, B. Mueller-Haye and H. I. Vecchionacce. 1972. La harina de yuca en el engorde de ceredos. Agronomia Tropical. 12:599.

Clawson, A. J., J. T. Reid, B. E. Sheffy and J. P. Willman. 1955. Use of chromium oxide in digestion studies with swine. J. Anim. Sci. 14:700.

Clemens, E. T., C. E. Stevens and M. Southworth. 1975. Sites of organic acid production and pattern of digesta movement in the gastrointestinal tract of swine. J. Nutr. 105:759.

Cole, D. J., A. J. E. Duckworth and W. Holmes. 1967a. Factors affecting voluntary feed intake in pigs. I. The effect of digestible energy content of the diet on the intake of castrated male pigs housed in holding pens and in metbolism crates. Anim. Prod. 9:141.

Cole, D. J., A. J. E. Duckworth and W. Holmes. 1967b. Factors affecting voluntary feed intake in pigs. II. The effect of two levels of crude fiber in the diet on the intake and performance of fattening pigs. Anim. Prod. 9:149.

Collings, G. F., J. P. Erickson, M. T. Yokayama and E. R. Miller. 1979. Effect of wheat middlings on fiber digestibility, serum cholesterol and glucose and fecal bile acids in pigs. J. Anim. Sci. 49:528.

Cooper, P. H. and C. Tyler. 1959a. Some effects of bran and cellulose on the water relationships in the digesta and feces of pigs. I. The effects of incuding bran and two forms of cellulose in otherwise normal rations. J. Agr. Sci. (Camb.). 52:332.

Cooper, P. H. and C. Tyler. 1959b. Some effects of bran and cellulose on the water relationships in the digesta and feces of pigs. II. The effects of adding different levels of fibrous cellulose to a highly digestible purified ration. J. Agr. Sci. (Camb.). 52:340.

Corley, J. R., R. A. Easter, M. A. Roos and G. C. Fahey, Jr. 1978. Effect of various fiber sources on gain, feed efficiency and nitrogen retention in the weanling pig. Nutr. Rep. Int. 18:135.

Coursey, D. G. 1973. Cassava as food: toxicity and technology. In Chronic Cassava Toxicity. Proc. Interdisciplinary Workshop. London. pp. 27-36.

Creswell, D. C. and C. C. Brooks. 1971a. Composition, apparent digestibility and energy evaluation of coconut oil and meal. J. Anim. Sci. 33:366.

Creswell, D. C. and C. C. Brooks. 1971b. Effect of coconut meal on coturnix quail and of coconut meal and coconut oil on performance, carcass measurements and fat composition in swine. J. Anim. Sci. 33:370.

Creswell, D. C., F. L. Calderon, J. H. Maner and H. D. Wallace. 1975. Methionine and iodine in cassava diets for rats and swine. J. Anim. Sci. 40:179 (Abstr.).

Cuca, M. and M. L. Sunde. 1967a. The availability of calcium from Mexican and Californian sesame meals. Poul. Sci. 46:994.

Cuca, M. and M. L. Sunde. 1967b. Amino acid supplementation of a sesame meal diet. Poul. Sci. 46:1512.

Cunningham, H. M., D. W. Friend and J. W. G. Nicholson. 1962. The effect of age, bodyweight, feed intake and adaptability of pigs on the digestibility and nutritive value of cellulose. Can. J. Anim. Sci. 42:167.

Daghir, N. J., M. F. Ullah and K. Rottensten. 1967. Lysine supplementation of sesame meal broiler rations. Trop. Agr. (Trinidad). 44:234.

Dahniya, M. T., C. O. Oputa and S. K. Hahn. 1981. Effects of harvesting frequency on leaf and root yields of cassava. Exp. Agr. 14:91.

Dale, N. M. and H. L. Fuller. 1980. Additivity of true metabolizable energy values as measured with roosters, broiler chicks and pullets. Poul. Sci. 59:1941.

Dale, N. M. and H. L. Fuller. 1981. The use of true metabolizable energy in formulating poultry rations. Proc. Georgia Nutr. Conf. pp. 50-57.

Danielson, D. M. and J. J. Noonan. 1975. Roughages in swine gestation diets. J. Anim. Sci. 41:94.

Davies, N. T. and R. Nightingale. 1975. The effects of phytate on intestinal absorption and secretion of zinc and whole-body retention of zinc, copper, iron and manganese in rats. Brit. J. Nutr. 34:243.

Eastwood, M. A. and D. Hamilton. 1968. Studies on the absorption of bile salts to non-absorbed components of the diet. Biochem. Biophys. Acta 152:165.

Edmundson, I. C., M. R. Patchell and R. D. King. 1978. Metabolizable energy. 7. Assays of ingredients and diets. Summary of final reports and current research. Poultry Res. Centre. Massey Univ. New Zealand.

Eggum, B. O. 1970. The protein quality of cassava leaves. Brit. J. Nutr. 24:761.

Ekpechi, O. L., A. Dimitriadon and R. Fraser. 1966. Goitrogenic activity of cassava. Nature (London). 210:1137.

Elsley, F. W. H., M. Bannerman, E. V. J. Bathurst, A. G. Bracewell, J. M. M. Cunningham, T. L. Dodsworth, P. A. Dodds, T. J. Forbes and R. Laird. 1969. The effect of level of feed intake in pregnancy and in lactation upon the productivity of sows. Anim. Prod. 11:225.

Engster, H. M., D. C. Snetsinger and J. W. Kessler. 1981. Commercial application of the TME system. Proc. 3rd Europ. Symp. Poultry Nutr. Cited by Sibbald, I. R. 1982. Feed Mgt. 33(1): 12.

Enriquez, F. Q. and E. Ross. 1967. The value of cassava root meal for chicks. Poul. Sci. 46:622.

Enriquez, F. Q. and E. Ross. 1972. Cassava root meal in grower and layer diets. Poul. Sci. 51:228.

Ershoff, B. H. 1960. Beneficial effects of alfalfa meal and other bulk-containing a bulk-forming materials on the toxicity of non-ionic surface-active agents in the rat. J. Nutr. 70:484.

Ershoff, B. H. 1974. Antitoxic effects of plant fiber. Amer. J. Clin. Nutr. 27:1395.

Evans, R. E. and M. F. Maguire. 1956. The influence of dietary antibiotics on the activity of the cellulose-splitting bacteria in the intestine of the bacon pig. J. Agr. Sci. (Camb.). 47:344.

Fahey, G. C., Jr., G. R. Frank, A. H. Jensen and S. S. Masters. 1980. Influence of various purified and isolated cell wall fibers on the utilization of certain nutrients by swine and hamsters. J. Food Sci. 45:1675.

Farrell, D. J. 1973. Digestibility by pigs of the major chemical components of diets high in plant cell wall constituents. Anim. Prod. 16:43.

Farrell, D. J. 1978. Rapid determination of metabolizable energy of foods using cockerels. Brit. Poult. Sci. 19:303.

Farrell, D. J. 1979. Energy systems for pigs and poultry: A review. J. Aust. Inst. Agr. Sci. 45:21.

Farrell, D. J. 1981. An assessment of quick bioassays for determining the true metabolizable energy and apparent metabolizable energy of poultry feedstuffs. Wld's Poul. Sci. J. 37:72.

Farrell, D.J. and K. A. Johnson. 1972. Utilization of cellulose by pigs and its effects on cecal function. Anim. Prod. 14:209.

Farrell, D.J. and S. Swain. 1977. Effects of temperature treatments on the heat production of starving cockerels. Brit. Poult. Sci. 18:725.

Fausch, H. D. 1981. The effect of Virginiamycin on rate of passage of ingesta in growing, finishing pigs. Proc. Symp. "Growth promotion mode of action". Kansas City, Missouri. p. 55.

Fetuga, B. L. and J. A. Oluyemi. 1976. The metabolizable energy of some tropical tuber meals for chicks. Poul. Sci. 55:868.

Fetuga, B. L., T. O. Ayeni, A. Olaniyan, M. A. Balogun, G. Babatunde and V. A. Oyenuga. 1977. Biological evaluation of para-rubber seeds. Nutr. Rep. Int. 15:497.

Fioramonti, J. and L. Bueno. 1980. Motor activity in the large intestine of the pig related to dietary fiber and retention time. Brit. J. Nutr. 43:155.

Fiske, C. H. and T. Subbarow. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66:374.

Forbes, R. M. and T. S. Hamilton. 1952. The utilization of certain cellulosic materials by swine. J. Anim. Sci. 11:480.

Fraps, G. S. 1946. Composition and productive energy of poultry feeds and rations. Texas Agr. Exp. Sta. Bull. 678.

Friend, D. W., J. W. G. Nicholson and H. M. Cunningham. 1964. Volatile fatty acid and lactic acid content of pig blood. Can. J. Anim. Sci. 44:303.

Frobish, L. T., N. C. Steele and R. J. Davey. 1973. Long-term effect of energy intake on reproductive performance of swine. J. Anim. Sci. 36:293.

Fronda, F. M. 1919. A study of the effects of animal and plant proteins in rations for laying hens. Philippine Agr. 7:235.

Fronda, F. M. and M. P. Mallonga. 1935. Protein supplements in poultry rations: V. Copra meal as a supplement in rations for growing chicks. Philippine Agr. 24:326.

Gallo, J. T. C. and J. H. Maner. 1970. Sesame meal for pigs. I. Nutritive value of sesame meal for growing and finishing pigs. Revista Instituto Colombiano Agropecuario. 5:107.

Gargallo, J. and D. R. Zimmerman. 1980. Effects of dietary cellulose and neomycin on function of the cecum in pigs. J. Anim. Sci. 51: 121.

Gargallo, J. and D. Zimmerman. 1981. Effect of sunflower hulls on large intestine functionality in finishing swine. J. Anim. Sci. 53:1286.

Garlich, J. D., D. M. Bryant, H. M. Covington, D. S. Chamblee and A. E. Purcell. 1974. Egg yolk and broiler skin pigmentation with sweet potato vine meal. Poul. Sci. 53:692.

Georgi, C. D. V., V. R. Greenstreet and L. T. Gunn. 1932. Storage of rubber seeds. Malaysian Agr. J. 20:164.

Gerpacio, A. L. 1979. The influence of cassava and sweet potato root meals on the availability of nutrients in mixed broiler rations and broiler performance. ASPAC Tech. Bul. No. 43. Taipei, Taiwan. pp. 13.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures and some applications). USDA Handbook No. 279, U.S. Printing Office. Washington, D.C.

Gohl, B. 1975. Tropical Feeds. FAO. Rome.

Gomez, G. 1979. Cassava as a swine feed. World Anim. Rev. 29:13.

Gorrill, A. D. L., J. M. Bell and C. M. Williams. 1960. Ingredient and processing interrelationships in swine feeds. III. Effects of wheat bran, pelleting and protein source on responses to dietary antibiotics. Can. J. Anim. Sci. 40:101.

Grau, C. R. and H. J. Almquist. 1944. Sesame meal protein in chick diets. Proc. Soc. Exp. Biol. Med. 57:187.

Grieve, C. M., D. F. Osbourn and F. O. Gonzales. 1966. Coconut oil meal in growing and finishing rations for swine. Trop. Agr. (Trinidad). 43:257.

Halloran, H. R. 1980. Comparison of metabolizable energy methods on identical ingredient samples. Poul. Sci. 59:1552.

Hamid, K. and S. Jalaludin. 1972. The utilization of tapioca in rations for laying poultry. Malaysian Agr. Res. 1:48.

Harmuth-Hoene, A. and R. Schelenz. 1980. Effect of dietary fiber on mineral absorption of growing rats. J. Nutr. 110:1774.

Hays, V. W. 1981. The Hays Report: Effectiveness of feed additive usage of antibacterial agents in swine and poultry production. Rachelle Laboratories, Inc., Long Beach, California.

Henderickx, H. K., I. J. Vervaecke, J. A. Decuypere and N. A. Dierick. 1981. Mode of action of growth promotion drugs. Proc. Symp. on 6th Promotion Mode-of-Action. Kansas city, Missouri. pp. 3-9.

Henry, Y. and M. Etienne. 1969. Effects nutritionnels de l'incorporation de cellulose purifee dans le regime du porc en croissance finition. I. Influence sur l'utilisation digestive des nutriments. Ann. Zootechnie. 18:337.

Henry, Y. 1971. Effects nutritionels de l'incorporation de cellulose purifice dans regime du porc en croissance. Ann. Zootechnie. 19:117.

Henry, Y. M. 1976. Prediction of energy values of feeds for swine from fiber content. Proc. 1st Int. Symp. on Feed Composition, Animal Requirements and Computerization of Diets. Logan, Utah. p. 270.

Hew, V. F. 1972. The utilization of cassava root meal in swine feeding. Malaysian Agr. Res. 1:124.

Hew, V. F. and R. I. Hutagalung. 1977. Utilization of cassava as a carbohydrate source of pigs. Proc. Fourth Int. Soc. Trop. Root Crops. Cali, Colombia. pp. 242-246.

Hill, F. W. and D. L. Anderson. 1958. Comparison of metabolizable energy and productive energy determinations with growing chicks. J. Nutr. 64:587.

Hill, D. C. 1973. Chronic cyanide toxicity in domestic animals. In Chronic Cassava Toxicity. Proc. Interdisciplinary Workshop. London, England, pp. 105-111.

Hubbell, C. H. 1980. Feedstuffs Analysis Table. Feedstuffs (USA). 52(3):42.

Hudson, B. J. F. and A. O. Ogunsu. 1974. Lipids of cassava tubers. J. Sci. Food Agr. 25:1503.

Hutagalung, R. T., S. Jalaludin and C. C. Chang. 1974. Evaluation of agricultural products and by-products as animal feeds. II. Effects of levels of dietary cassava leaf and root on performance, digestibility and body composition of broiler chicks. Malaysian Agr. Res. 3:49.

Imoto, S. and S. Namioka. 1978a. VFA production in the pig's large intestine. J. Anim. Sci. 57:467.

Imoto, S. and S. Namioka. 1978b. VFA metabolism in the pig. J. Anim. Sci. 47:479.

Ismail-Beigi, F., J. G. Reinhold, B. Faradji and P. Abadi. 1977. Effects of cellulose added to diets low and high fiber content upon the metabolism of Ca, Mg, Zn and P by man. J. Nutr. 107:510.

Jalaludin, S. and S. K. Leong. 1973. Response of laying hens to low and high levels of tapioca meal. Malaysian Agr. Res. 2:47.

Joachim, A. W. R. and D. G. Panditteseker e. 1944. Investigations of the hydrocyanic acid content of manioc. Trop. Agriculturist 100:150.

Job, T. A., J. A. Oluyemi, A. F. Awopeju and T. O. Odeyemi. 1980. Optimum level of cassava flour in the diet of the growing chick. Zbl. Vet. Med. A. 27:669.

Johnson, R. N. and W. D. Raymond. 1965. The chemical composition of some tropical food plants. IV. Manioc. Trop. Sci. 7:109.

Jones, W. O. 1959. Manioc in Africa. Stanford Univ. Press. Stanford. p. 315.

Kass, M. L., P. J. Van Soest, W. G. Pond, B. Lewis and R. E. McDowell. 1980a. Utilization of dietary fiber from alfalfa by growing swine. I. Apparent digestibility of diet components in specific segments of the gastrointestinal tract. J. Anim. Sci. 50:175.

Kass, M. L., P. J. Van Soest and W. G. Pond. 1980b. Utilization of dietary fiber from alfalfa by growing swine. II. Volatile fatty acid concentrations and disappearance from the gastrointestinal tract. J. Anim. Sci. 50:192.

Kennelly, J. J. and F. X. Aherne. 1980. The effect of fiber addition to diets formulated to contain different levels of energy and protein on growth and carcass quality of swine. Can. J. Anim. Sci. 60:389.

Keys, J. E., Jr., P. J. Van Soest and E. P. Young. 1970. Effect of increasing dietary cell wall content on the digestibility of hemicellulose and cellulose in swine and rats. J. Anim. Sci. 31:1172.

Keys, J. E. and J. V. DeBarthe. 1974. Cellulose and hemicellulose digestibility in the stomach, small intestine and large intestine of swine. J. Anim. Sci. 39:53.

Khajarern, S. and J. M. Khajarern. 1977. Use of cassava as a food supplement for broiler chicks. In Proc. 4th Symp. Int. Soc. Trop. Root Crops. Cali, Colombia. pp.246-250.

Khajarern, S., J. M. Khajarern, N. Kitpanit and Z. O. Muller. 1977. Cassava in the nutrition of swine. In Cassava as Animal Feed. Proceedings of a Workshop. Univ. of Guelph. Ontario. pp. 56-64.

Khajarern, S., J. Khajarern, N. K. Phalaraksh and N. Hutanuwata. 1979. Substitution of cassava root products for cereals in livestock and poultry feeds. ASPAC Extension Bull. 122. Taipei, Taiwan. p. 12.

Kies, C., H. M. Fox and D. Beshgetoor. 1979. Effects of various levels of dietary hemicellulose on zinc nutritional status of men. Cereal Chem. 56:133.

Kik, M. C. 1960. Effects of amino acid supplements, vitamin B_{12} and buffalo fish on the nutritive value of proteins in sesame seed and meal. J. Agr. Food Chem. 8:327.

King, R. H. and M. L. Taverner. 1975. Prediction of the digestible energy in pig diets from analysis of fiber contents. Anim. Prod. 21:275.

Klein, F. W. and C. V. Barlowen. 1954. Tapiokameal in aufzuchfutter. Arch. Geflugek. 18:415.

Kong, P., J. P. Mateo, D. E. Jewell and T. L. Veum. 1980. Effects of high levels of ground oats and feeding regimes on post weaning performance and incidence of scours. J. Anim. Sci. 51(Supp 1):75.

Kornegay, E. T. 1978. Feeding value and digestibility of soybean hulls for swine. J. Anim. Sci. 47:1272.

Kornegay, E. T., H. R. Thomas, S. R. Arthur, C. L. Gaines, K. L. Bryant and J. W. Knight. 1980. Pigs per cage, flooring materials and use of soybean hulls in starter diets for pigs housed in triple deck nurseries. J. Anim. Sci. 51:285.

Kornegay, E. T. 1981. Soybean hull digestibility by sows and feeding value for growing-fattening swine. J. Anim. Sci. 53:138.

Lang, J. A. and G. M. Briggs. 1976. The use and function of fiber in diets of monogastric animals. In Fiber in human nutrition. Ed. G. A. Spiller and R. J. Amen. Plenum Press. New York.

Lauw, T. G., S. Husaini and Z. Tarwotjo. 1967. Nutritional value of rubber seed protein. Amer. J. Clin. Nutr. 20:1300.

Lease, J. G., B. D. Barnett, E. J. Lease and D. E. Turk. 1960. The biological unavailability to the chick of zinc in a sesame meal ration. J. Nutr. 72:66.

Lease, J. G. 1966. The effect of autoclaving sesame meal on the phytic acid content and on the availability of its zinc to the chick. Poul. Sci. 45:237.

Lease, J. G. and W. P. Williams, Jr. 1967. Availability of zinc and comparison of in vitro and in vivo zinc uptake of certain oil seed meals. Poul. Sci. 46:233.

Lee, K. C. and R. I. Hutagalung. 1972. Nutritional value of tapioca leaf for swine. Malaysian Agr. Res. 2:47.

Le-Thuoc. 1968. Research on the use of rubber seed kernel as a protein supplement in livestock feeds. Ministry of Land Reform, Agric. Fisheries and A. H. devt. Vietnam.

Likuski, H. J. A., J. B. Bowland and R. T. Berg. 1961. Energy digestibility and nitrogen retention by pigs and rats fed diets containing non-nutritive diluents and varying protein level. Can. J. Anim. Sci. 41:89.

Likuski, H. J. A. and H. G. Dorrell. 1978. A bioassay for rapid determination of amino acid availability values. Poul. Sci. 57:1658.

Loosli, J. K., J. O. Pena, L. A. Ynalves and V. Villegas. 1954. The digestibility by swine of rice bran, copra meal, coconut meat, coconut residue and two concentrate mixtures. Philippine Agr. 38:191.

Luiza, V. M., C. Tupynamba and E. C. Vieira. 1979. Isolation of cassava leaf protein and determination of its nutritive value. Nutr. Rep. Int. 19:249.

Luyken, R., A. P. DeGroot and P. G. C. Van Stratum. 1961. Nutritional value of foods from New Guinea. II. Net protein utilization, digestibility and biological value of sweet potatoes and cassava leaves from New Guinea. Utrecht Central Inst. Nutr. and Food Res.

Maghuin-Rogister, G. 1968. A new disaccharide extracted from manioc flour. II. Synthesis of glucopyranosyl, d-glucofuranose. Bull.

Soc. Chem. Belgium. 77:575.

Mahadevan, P., D. G. Panditte Sekera, J. S. L. White and V. Arumugam. 1957. The effects of tropical feedstuffs on growth and first year of production. Poul. Sci. 36:286.

Mahendranathan, T. 1972. The effect of feeding tapioca leaves to pigs. Malaysian Agr. J. 48:77.

Malynicz, G. L. 1973. Coconut meal for growing pigs. Papua New Guinea Agr. J. 24:142.

Maner, J. H. 1973. Cassava in swine feeding. Bull. RB-1, Centro International de Agricultura Tropical, Cali, Colombia.

Maner, J. H. and G. Gomez. 1973. Implications of cyanide toxicity in animal feeding studies using high cassava rations. In Chronic Cassava Toxicity. Proc. Interdisciplinary Workshop. London, England. pp. 113-120.

Maner, J. H., J. Buitrago and I. Jimenez. 1967. Utilization of yuca in swine feeding. Proc. 1st Int. Symp. on Trop. Root Crops. U. of West Indies. Trinidad.

Mason, V. C., A. Just and S. Bech-Anderson. 1976. Bacterial activity in the hind gut of pigs. 2. Its influence on the apparent indigestibility of nitrogen and amino acids. Z. Tierphysiol. Tierernahr. Futtermittelk. 36:310.

Mateo, J. P., P. Kong, D. E. Jewell, J. T. Yen and T. L. Veum. 1980. Effect of dietary fiber source on performance of four week old pigs. J. Anim. Sci. 51(Suppl 1):74.

Maust, L. E., W. G. Pond and M. L. Scott. 1972a. Energy value of a cassava-rice bran diet with and without supplemental zinc for growing pigs. J. Anim. Sci. 35:953.

Maust, L. E., M. L. Scott and W. G. Pond. 1972b. The metabolizable energy of rice bran, cassava flour and blackeye cowpeas for growing chickens. Poul. Sci. 51:1397.

Maynard, L. A. and J. K. Loosli. 1969. Animal Nutrition. Sixth Edition. McGraw-Hill Book Company. New York.

McCance, R. A. and E. M. Widdowson. 1942. Absorption and excretion of zinc. Biochem. J. 36:692.

McLaren, G. A., S. L. Cuppett, J. E. Williams, G. C. Fahey, Jr. and T. R. Smith. 1974. Acid resistant hemicellulose fraction in rat nutrition. Nutr. Rep. Int. 10:163.

McLaren, G. A., J. E. Williams, G. C. Fahey, Jr., T. R. Smith, J. E. Smith and H. A. Woolf. 1976. Influence of acid-resistant hemicelluloses on urea nitrogen utilization by lambs. J. Anim. Sci. 43:1072.

Mee, J. M. L. and C. C. Brooks. 1973. Amino acid availability of coconut meal protein in swine. Nutr. Rep. Int. 8:261.

Mendeloff, A. Z. 1976. "Dietary Fiber". In Present Knowledge in Nutrition. The nutritional Foundation. Washington, D.C. p. 392.

Meyer, J. H. 1956. Influence of dietary fiber on metabolic and endogenous nitrogen excretion. J. Nutr. 58:407.

Miller, W. S. 1974. The determination of metabolizable energy. In Energy Requirements of Poultry. Eds. T. R. Morris and B. M. Freeman. British Poultry Science. Edinburg. pp. 91-112.

Mod, R. R., R. L. Ory, N. M. Morris and F. L. Normand. 1981. Chemical properties and interactions of rice hemicellulose with trace minerals in vitro. J. Agr. Food Chem. 29:449

Monte, W. C. 1981. Fiber: Its nutritional impact. J. Appl. Nutr. 33:63.

Montgomery, R. D. 1969. Cyanogens. In The Toxic Constituents of Plant Feedstuffs. Ed. E. Liener. Academic Press. New York.

Montilla, J. J., C. R. Mendez and H. Wiedenhofer. 1969. Utilizacion de la harina de tuberculo de yuca, en raciones iniciadoras para pollos de engorde. Arch. Latino American Nutr. 19:381.

Moore, C. P. 1976. The utilization of cassava forage in ruminant feeding. Proc. Int. Symp. Tropical Livestock Prod. Acapulco, Mexico.

Moser, B. D. 1981. Stress: Fiber sources in starter diets. Feed Industry. 57:16.

Muller, Z., K. C. Chou and K. C. Nah. 1975. Cassava as a total substitute for cereals in livestock and poultry rations. Proc. Conf. Anim. Feeds Trop. Sub-trop. Origin. Tropical Products Institute. London. pp. 85-95.

Murray, A. G. 1976. The effects of fiber in the form of various polysaccharides on the apparent digestibility of protein in the pig. Ph.D. Thesis. Aberdeen University, U.K.

Muztar, A. J. S. J. Slinger and J. H. Burton. 1977. Metabolizable energy content of fresh water plants in chickens and ducks. Poul. Sci. 56:1893.

Muztar, A. J. and S. J. Slinger. 1979. Effect of length of excreta collection period and feed input level on the true metabolizable energy value of rapeseed meal. Nutr. Rep. Int. 19:689.

Muztar, A. J. and S. J. Slinger. 1980. Effect of level of dietary fiber on nitrogen and amino acid excretion in the fasted mature rooster. Nutr. Rep. Int. 22:863.

Myer, R. O., P. R. Cheeke and W. H. Kennick. 1975. Utilization of alfalfa protein concentrate by swine. J. Anim. Sci. 40:885.

Naik, A. H. 1969. Chemical composition of Tanzanian feedstuffs. East Afric. Agr. J. 33:201.

Nartey, F. 1968. Studies on cassava Manihot Utillissima Pohl. 1. Cyanogenesis: The biosynthesis of linamarin and lotaustralis in etiolated seedlings. Phytochemistry 7:1307.

N.A.S. 1971. Atlas of nutritional data on United States and Canadian feeds. National Academy of Sciences. Washington, DC.

N.R.C. 1973. Nutrient requirements of domestic animals, No. 2. Nutrient requirements of swine. National Academy of Sciences - National Research Council. Washington, DC.

Ng, B. S. and R. I. Hutagalung. 1974. Evaluation of agricultural products and by-products. III. Influence of dehydrated poultry excreta supplementation in cassava diets on growth rate and feed utilization of chickens. Malaysian Agr. Res. 3:242.

Normanha, E. S. 1962. Meal of stalks and leaves of cassava. Agronomica. 14:16.

Obregon, B. R. 1968. Variation in the hydrocyanic acid content of 118 varieties of yuca. Agricultura Tropical. 24:51.

Oke, O. L. 1970. Toxic chemicals in Nigerian foodstuffs. Indian J. Nutr. Dietet. 7:117.

Oke, O. L. 1973. The mode of cyanide detoxification. In Chronic Cassava Toxicity. Proc. Interdisciplinary Workshop. London, England. p. 97.

Oke, O. L. 1978. Problems in the use of cassava as animal feed. Anim. Feed Sci. Tech. 3:345.

Olson, D. W., M. L. Sunde and H. R. Bird. 1969a. The metabolizable energy content and feeding value of mandioca meal in diets for chicks. Poul. Sci. 48:1445.

Olson, D. W., M. L. Sunde and H. R. Bird. 1969b. Amino acid supplementation of mandioca meal in chick diets. Poul. Sci. 48:1959.

Oluyemi, J. A., B. C. Fetuga and H. N. L. Endeley. 1976. The metabolizable energy value of some feed ingredients for young chicks. Poul. Sci. 55:611.

Onaghise, G. T. U. and J. P. Bowland. 1977. Influence of dietary faba beans and cassava on performance, energy and nitrogen digestibility and thyroid activity of growing pigs. Can. J. Anim. Sci. 57:159.

Ong, H. K. and S. W. Yeong. 1977. Prospects for the use of rubber seed meal for feeding pigs and poultry. Proc. Symp. Feedingstuffs for Livestock in Southeast Asia. Kualalampur. p. 337.

Orok, E. J. and J. P. Bowland. 1974a. Nigerian para rubber seed meal as an energy and protein source for rats fed soybean meal or peanut meal supplemented diets. Can. J. Anim. Sci. 54:239.

Orok, E. J. and J. P. Bowland. 1974b. Nigerian cocoa husks and cassava meal as sources of energy for rats fed soybean meal or peanut meal supplemented diets. Can. J. Anim. Sci. 54:229.

Otul, E. 1973. Study on the amino acid content of cassava leaves. In Abstracts on Cassava. Vol. II. CIAT. Cali, Columbia.

Owusu-Domfeh, K., D. A. Christensen and B. D. Owen. 1970. Nutritive value of some Ghanian feedstuffs. Can. J. Anim. Sci. 50:1.

Oyenuga, V. A. and L. K. Opeke. 1957. The value of cassava for pork and bacon production. West Afr. J. Biol. Chem. 1:3.

Oyenuga, V. A. 1961. Nutritive value of cereal and cassava diets for growing and fattening pigs in Nigeria. Brit. J. Nutr. 15:327.

Patrick. H. 1953. Deficiencies in a sesame meal type ration for chicks. Poul. Sci. 32:744.

Peers, D. G., G. M. Hillyer and A. Macandrew. 1978. The evaluation of grain distillers evaporated spent wash in diet for growing pigs. Anim. Prod. 26:396 (Abstr.).

Pollmann, D. S., D. M. Danielson and E. R. Peo, Jr. 1979. Value of high fiber diets for gravid swine. J. Anim. Sci. 48:1385.

Pollmann, D. S., D. M. Danielson, M. A. Crenshaw and E. R. Peo, Jr. 1980. Long-term effects of dietary additions of alfalfa and tallow on sow productive performance. J. Anim. Sci. 51:294.

Pond, W. G., R. S. Lowrey and J. H. Maner. 1962. Effect of crude fiber level on ration digestibility and performance in growing-fattening swine. J. Anim. Sci. 21:692.

Pond, W. G. and M. Kass. 1977. High fiber fiets for swine. Proc. Cornell Nutr. Conf. Cornell Univ. Ithaca, NY. p. 133.

Potter, L. M. 1972. The precision of measuring metabolizable energy in poultry feedstuffs. Feedstuffs (USA). 44(13):28.

Rajaguru, A. S. B. 1971. Effects of rubber seed meal on the performance of mature chicken. J. Nat. Agr. Soc. Ceylon. 8:38.

Rajaguru, A. S. B. 1972/73. Elimination of hydrocyanic acid from processed manioc chips. J. Nat. Agr. Soc. Ceylon. 9/10:53.

Rajaguru, A. S. B. 1975. Problem of HCN in cassava. Agric. Res. Seminar Series No. 75-7. Faculty of Agriculture. University of Sri Lanka. Peradeniya, Sri Lanka.

Rajaguru, A. S. B. 1977. Gingelly oil meal as a protein source for broiler chicken. J. Nat. Agr. Soc. Ceylon. 14:85.

Rajaguru, A. S. B. 1979. Manioc leaf meal as a protein supplement for broilers. J. Nat. Agr. Soc. Ceylon. 16:31.

Rajaguru, A. S. B. and S. G. De S. Wettimuny. 1971. Rubber seed meal as a protein supplement in poultry feeding. J. Nat. Agr. Soc. Ceylon. 8:1.

Rajaguru, A. S. B. and V. Ravindran. 1979. Rubber seed meal as a protein supplement in growing swine rations. J. Natl. Sci. Coun. Sri Lanka. 7:101.

Rajaguru, A. S. B., V. Ravindran, N. Sriskandarajah and W. V. D. A. Goonewardene. 1978. Use of poultry litter as a protein supplement in swine rations. J. Nat. Agr. Soc. Ceylon. 15:20.

Rajaguru, A. S. B., V. Ravindran and R. M. Ranaweera Banda. 1979. Manioc leaf meal as a source of protein for fattening swine. J. Natl. Sci. Coun. Sri Lanka. 7:105.

Rao, P. V. and S. Bose. 1970. The content of some of the essential amino acids in poultry feeds. Indian J. Nutr. Dietet. 7:300.

Real, C. D., T. D. Tanksley, Jr. and K. W. Purser. 1977. Effect of grain source, protein level and percentage of oats in starter diets for pigs weaned at four weeks of age. J. Anim. Sci. 45: (Suppl. 1):105.

Rerat, A. 1978. Digestion and absorption of carbohydrates and nitrogenous matters in the hind gut of the omnivorous non-ruminant animal. J. Anim. Sci. 46:1808.

Robertson, J. B. and P. J. Van Soest. 1977. Dietary fiber estimation in concentrate feedstuffs. J. Animal Sci. 45:(Suppl. 1):254.

Rogers, D. J. 1963. Studies on Manihot esculenta crantz and related species. Bull. Torrey. Bot. Club. 90:43.

Rogers, D. J. and M. Milner. 1963. Amino acid profile of manioc leaf protein in relation to nutritive value. Econ. Bot. 13:211.

Ross, E. and F. Q. Enriquez. 1969. The nutritive value of cassava leaf meal. Poul. Sci. 48:846.

Sambrook, I. E. 1979. Studies on digestion and absorption in the intestine of growing pigs. 8. Measurements of the flow of total lipid, acid-detergent fibre and volatile fatty acids. Brit. J. Nutr. 42:279.

Samson, A. S. 1971. Heat treatment of coconut meats and coconut meal. J. Sci. Food Agr. 22:312.

Sandel, E. G. 1950. Colorimetric determination of traces of metal. Interstate Publ. Inc. New York.

Schneeman, B. O. and D. Gallaher. 1980. Changes in small intestinal digestive enzyme activity and bile salts with dietary cellulose in rats. J. Nutr. 110:584.

Seerly, R. W. and R. C. Wahlstrom. 1965. Dehydrated alfalfa meal in rations for confined brood sows. J. Anim. Sci. 24:448.

Seerly, R. W., D. J. Rogers and F. C. Obioha. 1972. Biochemical properties and nutritive value of cassava. In A Literature Review and Research Recommendations on Cassava. U. of Georgia. p. 199.

Seerly, R. W., N. C. McDaniel and H. C. McCampbell. 1978. Environmental influence on utilization of energy in swine diets. J. Anim. Sci. 47:427.

Sherry, P. A., P. C. Harrison and E. C. Fahey, Jr. 1981. Dietary fiber and antibiotic interactions on nutritional and metabolic parameters in the growing pig. J. Anim. Sci. 53:1309.

Shires, A., A. R. Robblee, R. T. Hardin and D. R. Clandinin. 1980. Effect of age of chickens on the true metabolizable energy values of feed ingredients. Poul. Sci. 59:396.

Sibbald, I. R. 1975. The effect of level of feed intake on metabolizable energy values measured with adult roosters. Poul. Sci. 54:1990.

Sibbald, I. R. 1976a. A bioassay for true metabolizable energy in feedingstuffs. Poul. Sci. 55:303.

Sibbald, I. R. 1976b. The true metabolizable energy values of several feedstuffs measured with roosters, laying hens, turkeys and broiler hens. Poul. Sci. 55:1459.

Sibbald, I. R. 1976c. The effect of duration of starvation on the assay bird on true metabolizable energy values. Poul. Sci. 55:1578.

Sibbald, I. R. 1977a. The true metabolizable energy system. Part 2. Feedstuffs (USA). 49(43):23).

Sibbald, I. R. 1977b. The true metabolizable energy values of some feedingstuffs. Poul. Sci. 56:380.

Sibbald, I. R. 1978. Scientists study metabolizable energy variation in swine and poultry diets. Feedstuffs (USA). 50(48):20.

Sibbald, I. R. 1979a. Passage of feed through the adult rooster. Poul. Sci. 58:446.

Sibbald, I. R. 1979b. Metabolizable energy evaluation of poultry diets. In Recent Advances in Animal Nutrition - 1979. Eds. W. Haresign and D. Lewis. Butterworths. London. pp. 35-49.

Sibbald, I. R. 1979c. The effect of duration of the excreta collection period on the true metabolizable energy values of feedstuffs with slow rate of passage. Poul. Sci. 58:896.

Sibbald, I. R. 1980a. Metabolizable energy in poultry nutrition. Bioscience 30:736.

Sibbald, I. R. 1980b. The passage of oat and other feed residues through the adult cockerel. Poul. Sci. 59:2136.

Sibbald. I. R. 1980c. The effect of dietary cellulose and sand on the combined metabolic plus endogenous energy and amino acid outputs of adult cockerels. Poul. Sci. 59:836.

Sibbald, I. R. 1982. Evolution of the TME system. Feed Management (USA). 33(1):12.

Sibbald, I. R. and K. Price. 1978. The metabolic and endogenous losses of adult roosters. Poul. Sci. 57:556.

Sibbald, I. R. and J. K. G. Kramer. 1980. The effect of the basal diet on the utilization of fat as a source of true metabolizable energy, lipids and fatty acids. Poul. Sci. 59:316.

Sibbald, I. R. and K. Price. 1980. Variability in metabolic plus endogenous energy losses of adult cockerels and in the true metabolizable energy values and rates of passage of dehydrated alfalfa. Poul. Sci. 59:1275.

Siriwardene, J. A. De S and D. Nugara. 1972. Metabolizable energy of rubber seed meal in poultry diets. Ceylon Vet. J. 20:61.

Siriwardene, J. A. De S. and K. N. P. Ranaweera. 1974. Manioc leaf meal in poultry diets. Ceylon Vet. J. 22:53.

Smith, R. E. and H. M. Scott. 1965. Use of free amino acid concentrations in blood plasma in evaluating the amino acid adequacy of intact proteins for chick growth. II. Free amino acid patterns of blood plasma of chicks fed sesame and raw, heated and overheated soybean meals. J. Nutr. 86:45.

Soares, P. R., J. Compos and J. H. Conrad. 1968. Farelo integral de raspa de mandioca. Experientiae. 8:19.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co. San Francisco.

Soldevila, M. and M. P. Deporta. 1976. Effect of different levels of coconut meal on egg production. J. Agr. Univ. Puerto Rico. 60:635.

Spiller, G. A. and E. A. Shipley. 1977. Perspectives in dietary fiber in human nutrition. Wld. Rev. Nutr. Diet. 27:105.

Story, J. A. and D. Kritchevsky. 1976. Comparisons of the binding of various bile acids and bile salts in vitro by several types of fiber. J. Nutr. 106:1292.

Tanksley, T. D., Jr., G. L. Walch, K. W. Purser, C. E. Real and E. J. Gregg. 1978. Effect of starter diet on pig performance from weanling to market. J. Anim. Sci. 47(Suppl. 1):275.

Teague, H. S. 1955. The influence of alfalfa on ovulation rate and other reproductive phenomena in gilts. J. Anim. Sci. 14:621.

Teague, H. S. and A. P. Grifo. 1965. Vitamin intake and the nutritive contribution of alfalfa to successive generation performance of swine. J. Anim. Sci. 24:775.

Temperton, H. and F. J. Dudley. 1941. Research in poultry nutrition in wartime. Empire J. Exp. Agr. 36:248.

Thomas, W. G. 1977. Considerations for the use of cassava as the energy source in broiler rations fed in tropical and subtropical regions. Ph.D. Thesis. University of Illinois at Urbana-Champaign. p. 171.

Toma, R. B., M. M. Tabekhia and J. D. Williams. 1979. Phytate and oxalate contents in sesame seed. Nutr. Rep. Int. 20:20.

Van Soest, P. J. and J. B. Robertson. 1977. The role of fiber in gut fermentation. Proc. Symp. "Defining Fiber in Human Nutrition". 174th ACS Meeting. Chicago, Illinois.

Varon, I. A. 1968. Annual Report - Potato and Yuca Programs. ICA. Cali, Columbia.

Vellosa, L., A. J. Rodriguez, M. Becker, L. P. Neto, W. N. Scott, E. B. Kalil, L. Melotti and G. L. Da Roche. 1967. Substituicao parcial e total do milho pelo farelo de mandioca em racoes de suinos em cresciminento e engorda. Bol. Ind. Anim. 23:129.

Villegas, A. M., A. Gonzalez and R. Calderon. 1968. Microbiological and enzymatic evaluation of sesame protein. Cereal Chem. 45:379.

Visek, W. J. 1978. The mode of growth promotion by antibiotics. J. Anim. Sci. 46:1447.

Vohra, P. 1972. Evaluation of metabolizable energy for poultry. Wld's Poul. Sci. J. 59:204

Vohra, P. 1975. New sources of feedstuffs for poultry - carbohydrates in particular. Wld. Rev. Nutr. Diet. 22:93-151.

Vogt, H. 1966. The use of tapioca meal in poultry rations. Wld's Poul. Sci. J. 22:113.

Wahlstrom, R. C., L. J. Reiner and G. W. Libal. 1977. Oats, dehulled oats and hulless barley as ingredients in pigs starter diets. J. Anim. Sci. 45:948.

Walter, W. M., Jr., A. E. Purcell and G. K. McCollum. 1978. Laboratory preparation of a protein-xanthophyll concentrate from sweet potato leaves. J. Agr. Food Chem. 26:1222.

Weiss, E. A. 1971. Castor, Sesame and Safflower. Barnes and Noble, Inc. New York.

Whitehouse, F. R., A. Zarrow and H. Shay. 1945. Rapid method of determining "crude fiber" in distillers' dried grain. J. Assoc. Official Agr. Chem. 28:147.

Whiting, F. and M. Bezeau. 1957. The metabolic fecal nitrogen excretion of the pig as influenced by the amount of fiber in the ration and by bodyweight. Can. J. Anim. Sci. 37:95.

Williams, R. D. and Olmsted, W. H. 1936. The effect of cellulose, hemicellulose and lignin on the weight of stool. A contribution to the study of laxation in man. J. Nutr. 11:433.

Wyllie, D. and F. P. Lekule. 1980. Cassava and molasses for fattening pigs under village conditions in Tanzania. Trop. Agr. (Trinidad). 57:267.

Yoshida, M., H. Hoshii, K. Kosaka and H. Morimoto. 1966. Nutritive value of various energy sources for poultry feed. IV. Estimation of available energy of cassava meal. Jap. Poul. Sci. 3:29.

Young, L. G. 1980. Lysine addition and pelleting of diets containing wheat shorts for growing-finishing pigs. J. Anim. Sci. 51:1113.

APPENDIX

TABLE 1. VARIABILITY IN THE DRY MATTER DIGESTIBILITY AND TRUE METABOLIZABLE ENERGY VALUES OF CASSAVA LEAF MEAL

Bird No.	% DMD		TME (kcal/kg)	
	24 hr	48 hr	24 hr	48 hr
1	24.80	26.65	2385	1727
2	41.33	26.67	2439	1897
3	81.99	25.58	4242	1810
4	25.43	25.39	2454	1832
5	53.77	52.47	2832	2471
6	56.43	50.49	2798	2182

TABLE 2. METABOLIZABLE ENERGY, METABOLIZABLE ENERGY CORRECTED FOR NITROGEN EQUILIBRIUM, TRUE METABOLIZABLE ENERGY AND TRUE METABOLIZABLE ENERGY CORRECTED FOR NITROGEN EQUILIBRIUM VALUES[a] (MEAN ± SD) OF THREE TROPICAL FEEDSTUFFS

Feedstuff	ME[b]	ME_n[c]	TME[d]	TME_n[e]
Cassava tuber meal[f]	3.29 ± .06	3.50 ± .06	3.76 ± .06	3.73 ± .06
Cassava leaf meal[g]	.77 ± .31	1.25 ± .23	1.99 ± .28	1.82 ± .27
Sesame oil meal[f]	1.96 ± .09	1.90 ± .08	2.42 ± .09	2.13 ± .08

[a]Expressed as kcal/g.

[b]$ME = \frac{EI-FE}{DMI}$, where EI, FE and DMI represent energy intake, fecal energy excretion of fed birds and dry matter intake, respectively.

[c]$ME_n = \frac{EI-(FE \pm 8.22\ N_f)}{DMI}$, where N_f represents the g N retained by fed-birds. N retained was assumed to produce to additional urinary energy in the excreta amounting to 8.22 kcal per g N.

[d]$TME = \frac{EI-(FE-EE_u)}{DMI}$, where EE_u equals the energy excretion by the fasted birds.

[e]$TME_n = \frac{EI-(FE \pm 8.22\ N_f) + (EE_u \pm 8.22\ N_u)}{DMI}$, where N_u equals the g N retained by the fasted birds.

[f,g]Values based on 24 and 48 hour collection periods, respectively.

TABLE 3. DRY MATTER INTAKE, CRUDE PROTEIN AND GROSS ENERGY CONTENTS OF THE FEEDSTUFFS IN TME BIOASSAY

Bird No.	Body Weight (kg)	Treatment	Dry Matter Intake (g)	Crude Protein, %[a]	Energy (kcal/kg)[a]
1	1.89	Control	-	-	-
2	1.98	CTM	20.59	2.9	4.09
3	1.74	SOM	21.40	35.2	3.94
4	2.00	CTM	21.89	2.9	4.09
5	1.97	CLM	21.05	20.2	4.88
6	2.36	SOM	21.93	35.2	3.94
7	1.93	SOM	22.30	35.2	3.94
8	2.10	CTM	21.74	2.9	4.09
9	2.67	Control	-	-	-
10	2.56	CTM	21.71	2.9	4.09
11	2.13	CLM	23.25	20.2	4.88
12	2.18	SOM	22.58	35.2	3.94
13	2.12	Control	-	-	-
14	2.31	CTM	22.16	2.9	4.09
15	2.34	CLM	19.66	20.2	4.88
16	2.14	Control	-	-	-
17	2.64	CLM	23.24	20.2	4.88
18	1.75	Control	-	-	-
19	1.64	CLM	16.98	20.2	4.88
20	2.47	SOM	22.18	35.2	3.94
21	2.11	CLM	11.59	20.2	4.88
22	1.64	CTM	22.00	2.9	4.09
23	2.06	SOM	22.04	35.2	3.94
24	1.96	Control	-	-	-

[a]As fed basis.

TABLE 4. DRY MATTER OUTPUT, CRUDE PROTEIN AND ENERGY CONTENTS OF EXCRETA IN THE TME BIOASSAY, 0-24 HOURS

Bird No.	Dry Matter Output (g)	Crude Protein, %[a]	Energy (kcal/kg)[a]
1	2.91	120.8	2.57
2	4.54	89.8	3.41
3	15.10	40.2	2.80
4	4.87	84.2	3.32
5	19.19	41.1	3.89
6	15.31	43.2	2.68
7	15.66	43.1	2.77
8	5.04	80.4	3.73
9	2.75	133.4	3.18
10	5.31	76.5	3.29
11	23.25	43.8	3.93
12	15.26	39.5	2.83
13	4.23	117.6	2.99
14	5.43	75.3	3.53
15	19.66	95.5	3.28
16	3.32	113.7	3.19
17	23.24	34.1	3.79
18	3.03	122.6	3.04
19	16.98	47.7	4.01
20	15.70	40.8	2.96
21	11.59	50.7	4.08
22	5.07	81.1	3.35
23	15.83	40.6	2.90
24	3.92	116.3	3.19

[a]As fed basis.

TABLE 5. DRY MATTER OUTPUT, CRUDE PROTEIN AND ENERGY CONTENTS OF EXCRETA IN THE TME BIOASSAY, 24-48 HOURS

Bird No.	Dry Matter Output (g)	Crude Protein, %[a]	Energy (Kcal/kg)[a]
1	4.53	129.0	2.70
2	4.07	-	3.01
3	2.55	-	2.76
4	2.69	-	3.86
5	3.76	83.4	3.68
6	3.49	-	3.37
7	3.75	-	3.21
8	2.96	-	3.46
9	3.60	130.7	3.16
10	3.60	-	3.23
11	7.56	64.0	3.25
12	4.33	-	2.96
13	4.76	122.9	2.77
14	3.34	-	3.14
15	15.24	68.6	3.92
16	3.84	112.3	3.01
17	4.16	32.5	3.46
18	3.41	118.0	2.93
19	5.21	93.5	3.48
20	4.60	-	2.79
21	4.78	100.0	4.00
22	6.38	-	2.78
23	3.72	-	3.01
24	4.75	113.5	2.86

[a]As fed basis.

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METHODOLOGY TO EVALUATE THE NUTRITIVE VALUE OF FEEDSTUFFS FOR POULTRY AND SWINE

by

Velmurugu Ravindran

(ABSTRACT)

Six tropical feedstuffs were analyzed for proximate composition, Van Soest components, mineral contents and amino acid composition. The crude protein contents (dry basis) of cassava tuber meal, sesame oil meal, coconut oil meal, rubber seed meal, cassava leaf meal and sweet potato leaf meal were 2.9, 35.2, 21.8, 12.0, 20.2 and 10.4%, respectively. The corresponding values for acid detergent fiber were 5.0, 23.5, 29.4, 39.1, 35.0 and 46.4%, respectively. Cassava tuber meal contained 88.4% nitrogen-free extract, but was poor in minerals and amino acids. Sesame oil meal had a silica content of 12.2% possibly indicating adulteration with sand; it was rich in all the minerals, especially Ca (2.32%), Mg (.56%), P (1.04%) and Fe (.32%). Coconut oil meal contained high amounts of Na (852 ppm) and K (1.83%), whereas the Zn (249 ppm) and Mn (252 ppm) were higher in cassava leaf meal. With the possible exception of sesame oil meal, the sulphur amino acids are likely to be the most limiting when these feedstuffs are fed to livestock.

True metabolizable energy (TME) values of cassava tuber meal, cassava leaf meal and sesame oil meal were determined using 24 adult Single Comb White Leghorn roosters. After 24 hours of fasting, six roosters were force-fed 25 g of each of these feedstuffs. Six roosters

were fasted for another 48-hour period and served as negative controls. Excreta were collected for two consecutive 24-hour periods. Length of collection period had no effect on the TME of cassava tuber meal and sesame oil meal, indicating that a 24-hour collection period was adequate for these feedstuffs. A collection period of 48 hours or longer was, however, required for roosters force-fed cassava leaf meal. The mean TME values (dry basis) of cassava tuber meal, cassava leaf meal and sesame oil meal were determined to be 3.76 ± .06, 1.99 ± .28 and 2.42 ± .09 kcal/g, respectively.

Three digestion trials, each involving 12 crossbred gilts averaging 35.2 kg body weight, were conducted to determine the effects of crude fiber and Virginiamycin on digesta rate of passate (RP) and nutritional parameters. Two levels (3.2 and 7.3%) of crude fiber and two levels (0 and 11 ppm) of Virginiamycin were used in a 2 x 2 factorial arrangement of treatments. All diets were isonitrogenous and isocaloric. RP was determined by noting the time required for a change in feces color following the addition of 0.5% chromic oxide to the diet. The high fiber diet had a faster ($P<.001$) RP and this was associated with depressions ($P<.001$) in the digestibility of dry matter (DM), energy (E), cell content, cell wall (CW), acid detergent fiber (ADF), hemicellulose, cellulose, lignin and ash. Virginiamycin supplementation slowed ($P<.01$) the RP of both low and high fiber diets, but improved ($P<.10$) the DM, E and CW digestibility of the high fiber diet only. Non-significant improvements ($P<.15$) in the digestibility of ADF and cellulose were also observed when Virginiamycin was supplemented to the high fiber diet. Fiber increased ($P<.05$) fecal nitrogen, whereas Virginiamycin supplemen-

tation decreased ($P<.05$) fecal nitrogen. Results suggest that Virginiamycin supplementation improved the energy utilization in a high fiber diet, but had little effect on a low fiber diet.

A study was conducted, concurrent to the first total collection digestion trial, to evaluate the applicability of chromic oxide indicator method to estimate the digestibility of nutrients. Digestion coefficients derived from the indicator method were in close agreement with those determined by the conventional total collection method for the low fiber diet, but underestimate the values for the high fiber diet.