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*REVIEW*

# UTILIZATION OF CASSAVA (*MANIHOT ESCULENTA* CRANTZ) LEAVES IN ANIMAL NUTRITION

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**Abstract:** The nutrient composition of cassava (**Manihot esculenta** Crantz) leaves and their usefulness as a protein supplement in animal nutrition is reviewed. Leaf productivity and protein content may be increased by exploiting natural genetic variability and by manipulating agronomic practices. The presence of hydrocyanic acid and tannins is discussed, but a leaf meal with low levels of these anti-nutritional factors may be prepared using simple processing methods. Immediate prospects for the use of cassava leaf products are in the following areas: (1) low level inclusion of leaf meal in feed formulations for monogastric animals, and (2) fresh forage as a protein supplement to low-quality roughage in ruminant feeding. Relevant future research needs are also identified.

## INTRODUCTION

Attempts to expand the animal husbandry in tropical developing countries have been hampered by increasing cost and chronic shortage of traditional feed resources. Seasonal and unreliable rainfall, marginal soil fertility and subsistence farming result in an erratic supply of locally grown feeds. Nevertheless there exists a wide spectrum of agricultural by-products, some of which are available in large quantities and have considerable nutritional potential. Cassava (*Manihot esculenta* Crantz) leaves are an example of such unrealized potential.

The high protein content of cassava leaves is well documented. The potential yields of cassava leaves as by-product at root harvesting may amount to as much as 4.64 tonnes dry matter per hectare.[1] The current practice, in most instances, is to return this valuable resource to the soil as a green manure. It is the intent of the present paper to review the use of cassava leaves as an animal feed and, to examine their potential in ruminant and monogastric animal production systems in the tropics. Fresh cassava forage, including tender stems, could be utilized directly for ruminant feeding. For monogastric animals, however, the leaves have to be processed into a dehydrated leaf meal. The review also discusses methods of processing cassava leaves, with emphasis on removing hydrocyanic acid.

## Cassava Leaves

The cassava plant is a shrubby, woody, short-lived perennial growing to a height of 3 m or more, with erect stems and varying degrees of branching. In some cultivars, branches are produced only from the base of the stem giving an erect bunch growth habit. In others, the branching pattern and branch growth produce widely spreading plants. The stems are slender with leaves clustered towards the apex and with prominent leaf scars lower down. The large, palmate leaves are arranged spirally on the stems and have long petioles. The leaf blade is deeply divided into 5 to 7 obovate - lanceolate lobes of up to 20 cm long. The leaves are usually dark green in colour, but various shades of red, yellow and purple pigmentation may occur.[2,3]

The mean proportion of different parts of cassava plant at root maturity (11-12 months) is shown in Figure 1. The amount of forage available at root harvest is equivalent to about 30% of the root yields.

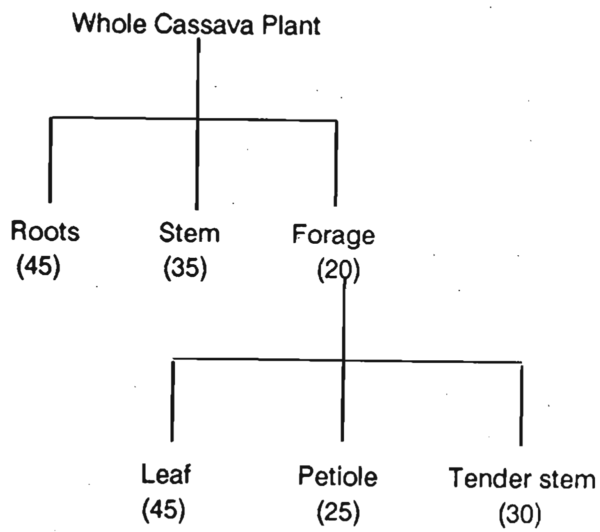


**Figure 1: Percentage by weight of the components of cassava plant at root maturity (average of 12 cultivars).**

## Nutrient Composition

The protein content of cassava leaves is high for a non-leguminous plant (Table 1). Cassava leaves contain an average of 21% crude protein, but values ranging from 14.7 - 40.0% have been reported.[4] This wide variability is related to differences in cultivars,[5,6,7] stage of maturity,[8] sampling procedure,[9] soil fertility and climate.[10] Variations in leaf protein content between cultivars have been studied by several researchers. Rogers,[6] who analyzed 60 cultivars, found a range of 20.6 - 30.4% crude protein on a dry weight basis. In a subsequent study involving 20 cultivars, Rogers and Milner[11] reported a greater variability of 17.8 - 34.8%. While part of this variability may reflect cultivar differences, it appears that sampling procedures, especially of leaves at different stages of maturity, may also have contributed to the observed differences. Ravindran and Ravindran[8] found that the crude protein content decreased from 38.1% in very young leaves to 19.7% in mature leaves. Almost 85% of the crude protein fraction is true protein.[12] The possibility of increasing the leaf protein content by breeding has been explored.[4] Crossing cassava cultivars with other Manihot species resulted in hybrids with leaf protein content well above that of the superior parent. The protein content of the roots was also increased, but this was accompanied by significant increases in the HCN content of the roots. The leaves were not analyzed for HCN levels in this study. However, it is noteworthy that Rogers[6], analyzing about 60 cultivars, failed to find any correlation between the HCN and protein contents of cassava leaves.

**Table 1: Proximate composition and metabolizable energy values of cassava leaf meal and alfalfa meal.**

| | Cassava leaf meal | Alfalfa meal[a] |
|---|---|---|
| Dry matter, % | 93.0 | 93.1 |
| Crude Protein, % | 21.0 (16.7-39.9)[b] | 20.0 |
| Crude fat, % | 5.5 (3.8-10.5) | 3.5 |
| Crude fibre, % | 20.0 (4.8-29.0) | 20.0 |
| Ash, % | 8.5 (5.7-12.5) | 10.5 |
| Metabolizable energy (k cal/kg) | | |
| Poultry | 1.80 (1.59-1.90) | 1.63 |
| Swine | 2.16[c] | 2.03 |

[a] Allen[68]

[b] Values in parantheses refer to ranges reported in literature; compiled from sources cited in the text.

[c] Ravindran[78]

Little or no attempt has been made so far to select for high leaf protein content as the primary aim was to produce low cyanide cultivars with high root yields.[13, 14] The genetic variability that exists between cultivars in leaf protein content is suggestive of the potential response to selection and this appears to be a fruitful area for further research. Optimization of cultural practices such as fertilizer application may offer another means of increasing the protein content of cassava leaves. Evidence shows that leaf protein content is influenced by water availability and soil fertility.[10]

Although cassava leaves are rich in protein, factors such as high crude fibre may limit their nutritive value for monogastric animals. Rogers and Milner,[11] analyzing 20 cultivars, reported a range of 4.0 - 15.2%. Immature cassava leaves were evidently used in the above analyses, since values as high as 29.0% have been reported for mature leaves.[15] Stage of maturity is the major factor contributing to the variability in fibre content, but environmental and cultivar effects are also implicated.[11]

Cassava leaf meal contains about 6% ether extractable fraction, but only a half of this is lipids. Khor and Tan[16] reported the lipid content of cassava leaves to be 3.0%. The lipids consisted of 20.0% non-polar lipids, 25.1% glycolipids and 48.2% phospholipids. All lipids, except steryl esters, were rich in polyunsaturated fatty acids.

Cassava leaves are good sources of minerals. They are particularly rich in calcium, magnesium, iron, manganese and zinc (Table 2). But the mineral profile can vary considerably depending on soil fertility and leaf maturity.[8] Cassava leaves are also rich in ascorbic acid[17] and vitamin A,[18] and contain significant amounts of riboflavin.[19] But considerable losses of vitamins, particularly of ascorbic acid, occur during processing.[20]

**Table 2: Mineral contents of cassava leaf meal and alfalfa meal.**

| | Cassava leaf meal[a] | Alfalfa meal[b] |
|---|---|---|
| Macrominerals, % | | |
| Potassium | 1.28 | 2.50 |
| Calcium | 1.45 | 1.50 |
| Magnesium | 0.42 | 0.32 |
| Phosphorus | 0.45 | 0.25 |
| Sodium | 0.02 | 0.08 |
| Microminerals, mg/kg | | |
| Zinc | 149 | 19 |
| Manganess | 52 | 34 |
| Iron | 259 | 281 |
| Copper | 12 | 9 |

[a] Ravindran et al.[15]
[b] Allen[68]

## Amino Acid Composition

Rogers and Milner[11] were the first to conduct detailed analyses of the amino acid content of cassava leaves. They analysed the leaves of 20 Jamaican and Brazilian cultivars obtained from ten month old healthy cassava plants and found that cassava leaf protein was deficient in methionine, possibly marginal in tryphtophan, but rich in lysine. Later studies[7,8,12,21] on cassava leaf protein showed similar amino acid patterns, although considerable variability was observed for individual amino acids. The variation in amino acid content of the leaves may be attributed to the stage of leaf maturity, sampling procedures, analytical methods and ecological conditions. Yeoh and Chew[7] observed that variation among cultivars grown under identical conditions was insignificant, suggesting little, if any, genotypic variation with respect to amino acid content. In contrast the data of Rogers and Milner[11] suggest that there is a large variability in the amounts of individual amino acids between cultivars. However, these authors did not mention whether these cultivars were grown under similar conditions and sampled in an identical manner.

The changes in amino acid composition in relation to maturity of leaves have been studied by Ravindran and Ravindran.[8] As the leaves matured, the general trend was for the amino acid concentrations to decrease. Only the non essential amino acids, glutamic acid, proline and glycine, increased, while valine and phenylalanine were unaffected. Of the essential amino acids, lysine and histidine showed the greatest decrease. The essential amino acid profile of cassava leaf meal compares favourably with that of alfalfa meal (Table 3).

**Table 3: Essential amino acid profile of cassava leaf meal and alfalfa meal (g/16 g N).**

| | Cassava leaf meal[a] | Alfalfa meal[b] |
|---|---|---|
| Arginine | 5.3 (4.0 - 5.7) | 4.9 |
| Lysine | 5.9 (3.8 - 7.5) | 4.4 |
| Methionine | 1.9 (1.3 - 2.0) | 1.7 |
| Cystine | 1.4 (0.7 - 1.4) | 1.2 |
| Total sulphur amino acids | 3.3 (2.0 - 3.3) | 2.9 |
| Tryptophan | 2.0 | 2.3 |
| Histidine | 2.3 (1.1 - 2.5) | 2.1 |
| Isoleucine | 4.5 (3.9 - 5.0) | 4.9 |
| Leucine | 8.2 (7.2 - 8.9) | 7.5 |
| Phenylalanine | 5.4 (5.3 - 5.4) | 5.2 |
| Threonine | 4.4 (3.2 - 5.0) | 4.4 |
| Valine | 5.6 (5.1 - 5.7) | 6.0 |

[a] Eggum[12]

[b] Allen[68]

[c] Values in parantheses refer to ranges reported in the literature; compiled from sources cited in the text.

**Protein Quality**

The digestibility of cassava leaf protein for rats has been investigated by Luyken *et al.*,[22] who found the digestibility to be 81% in young leaves and 76% in older leaves. However, the net protein utilization was low, 32% in young leaves and 39% in older leaves. Net protein utilization was increased to 61% by the addition of the most limiting amino acid methionine. Ravindran *et al.*[23] reported the protein digestibility of mature cassava leaves for poultry to be 63%.

Eggum,[12] using rat bioassays, studied the nutritional availability of individual amino acids in cassava leaves. The availability of amino acids varied widely ranging from 55% for valine and isoleucine to 84% for serine. Only 59% of the methionine was biologically available, resulting in a low biological value of 49 - 57%. Supplementation with methionine improved the biological value to 80%.

Oke[24] attributed the low protein digestibility values to the higher fibre content of cassava leaf meal. The presence of condensed tannins in cassava leaves[25] may be another factor responsible for the low protein utilization in cassava leaves. Tannins are known to lower the protein digestibility and amino acid availability by forming indigestible tannin-protein complexes with dietary proteins and/or by inhibiting digestive enzymes.[26]

**Productivity of Cassava Leaves**

The potential yield of cassava leaves varies considerably, depending on cultivars, age of plant, plant density, soil fertility, harvesting frequency and climate.[27-30] Ahmad[27] investigating the leaf dry matter productivity of two 12-month cultivars, reported yields of up to 7.5 t/ha. In this study, five leaf harvests were made at intervals of six weeks starting from three months after planting. Leaf harvesting, however, lowered the root crop to almost one-half of the normal yield. Normanha[31] harvested 9.0 t dry matter/ha in two harvests over a two-year period and obtained within 30% of the normal yield of roots.

The leaf dry matter yields are generally lower,if cassava leaves are to be obtained as a by-product at root harvest. Gomez and Valdivieso[29] evaluating two 12-month cultivars, reported the leaf dry matter yields at root maturity to be only 1.2 - 1.8 t/ha. In contrast, Ravindran and Rajaguru[1] obtained a much higher leaf dry matter yield of 4.64 t/ha. The higher yields in the latter study may be related to agronomic, climatic and soil fertility differences.

Leaf production can be enhanced by harvesting cassava leaves during the growing season, but this adversely affects root yields.[27,31] Cassava is cultivated primarily for its roots and it is therefore imperative that leaf harvesting should not greatly reduce root yields. Several studies have demonstrated that it is possible to harvest cassava leaves while maintaining acceptable yields of roots. Ravindran and Rajaguru[1] harvested 6.75 tonnes dry matter/ha by defoliating once during a seven-month growing season and obtained within 86% of the normal yields of roots. Dahniya *et al.*[28] defoliated twice during the growing season, starting from 4 months, for best all-round yields of roots and leaves in 12-month cultivars. However, the variation that appears to exist among cultivars in their tolerance to defoliation needs be taken into consideration before making any recommendation of harvesting frequency.

When the cultivation of cassava is exclusively aimed towards leaf production, the plant density could be increased and the harvesting frequency can be made shorter. Foliage can be harvested from 4 months of age in a cycle of 60 -75 days. With adequate irrigation and fertilization, cassava plants can withstand this defoliation for several years.[32] Under such conditions, annual leaf dry matter yields of over 21 tonnes per hectare can be obtained. This corresponds to a possible production of about 4 tonnes of protein per hectare per year.[30] Meyreles and Macleod, cited by Montaldo,[32] evaluated different plant densities to produce cassava foliage as a protein sources for animal feeding. They concluded that the best density was 60,000 plants/ha and that the foliage could be harvested every 5 months from the age of 3 months. Whether the aim of cassava cultivation under a given situation should be roots, leaves or production of both would depend *inter alia* upon the relative prices of cassava roots, cassava leaf meal and traditional feedstuffs. Data on the economics of cassava foliage production however, are scanty. Montaldo[32] calculated the cost of production of dried leaf meal under Venezuelan conditions and concluded that cassava leaf protein would be much cheaper than alfalfa for animal feeding in the tropics. Moore[10] estimated that cassava forage is a more economical source of nitrogen for cattle in Colombia than cotton seed meal.

### Cyanogenic Glucosides

The toxic properties of fresh cassava leaves are associated with the free HCN that is liberated when their cyanogenic glucosides, linamarin and lotaustralin, are hydrolyzed. The release of free HCN is brought about by the action of either the endogenous enzyme linamarase in damaged plant tissues or $\beta$-glucosidases within the digestive tract of animals. The linamarase and glucosides do not come into contact in healthy cassava leaves, but contact occurs when the tissues are mechanically damaged or when the physiological integrity is lost as in the case of wilted leaves.

The cyanide content of cassava leaves has been extensively studied. The normal range of cyanide content is from 20-80 mg HCN per 100g fresh leaf weight, but samples as low as 8 mg/100 g[33] or over 400 mg/100 g[8] have also been reported. On a dry basis (assuming 25% dry matter in fresh leaves), the normal range of HCN content would correspond to 800 - 3200 mg/kg. These levels are substantially higher than the normal range of HCN reported for fresh cassava roots.[34] Yeoh and Oh[35] found the leaf HCN levels to be six times higher than those of roots.

The wide variations observed in leaf cyanide levels may be attributed to genetic, physiological, edaphic and climatic differences, but have been exaggerated by problems associated with methodology of cyanide assay.[36] That there is considerable genetic component in the variation of leaf cyanide levels is now well established. Chew[37] reported a range of 17.4-62.2 mg HCN/100 g fresh weight in 18 cultivars grown under identical conditions. In a similar study involving 31 cultivars, Yeoh and Oh[35] obtained a range of 12.5 - 85.4 mg HCN/100 g fresh weight. Leaf has been postulated as the site of glucoside synthesis.[38] The rates of glucoside synthesis are similar in most cultivars, but differences between cultivars exist in the rate of degradation.[39] Cultivars with low leaf cyanide levels evidently have higher rates of degradation of glucoside.

Stage of leaf maturity is another important factor causing variations in cyanide content. As in other cyanogenic plants, the glucoside concentration in cassava leaves decreases with age. [8,9] In young expanding leaves, the cyanide levels in petioles is higher than those in leaf blades, whereas the reverse is true in older leaves.[39]

Cyanide levels in the leaves are also influenced by the nutritional status of the plant. De Bruijn[39] reported that leaf cyanide levels were increased by fertilizer nitrogen, whereas potassium and farmyard manure had the opposite effect. The effect of phosphate, calcium and magnesium was insignificant. Nitrogen and potassium are postulated to exert their influence by changing the amino acid content of the leaves, particularly valine and isoleucine, which may be the precursors of linamarin.[40] Sinha[41] suggested that a change in the method of fertilizer nitrogen application, from soil to foliar, may check enhanced cyanogenesis caused by fertilizer nitrogen.

Leaves produced during prolonged drought were reported to have a high cyanide content.[39] Short periods of water deficit generally have little effect as the plants adapt by abscessing leaves. Shading young plants caused an increase in the leaf cyanide levels.[39] There is evidence for a diurnal rhythm in cyanogenesis in cassava.[42] Goats and sheep browse cassava leaves at certain times of the day without any signs of toxicity, while ingestion during certain other times leads to poisoning and death.

Leaf cyanide levels have been screened[14,43] to select cultivars with low root cyanide content for breeding experiments. This procedure is convenient because leaves are more easily accessible than roots. Available data, however, suggest that no significant relationship exists between the cyanide content in leaves and roots.[35,41]

**Cyanide Toxicity**

Animals detoxify cyanide *via* several path ways, but primarily by reaction with thiosulphate to form thiocyanate. When cyanide is converted to thiocyanate, a 200-fold reduction in toxicity occurs. The body copes with small amounts of ingested cyanide in this manner. Thiocyanate is a potent goitrogen and has been implicated in the etiology of goitre in animals [44-46] and humans.[47]

While acute cases of cyanide toxicity usually result in sudden death of animals, less severe cases can result in gastrointestinal disorders and growth depression.[48] Despite its HCN content, documented cases of poisoning due to cassava leaves are not common. Perhaps the high content of HCN acts as a deterrent against excessive consumption of cassava leaves by grazing animals.[49]

**Tannins**

All plant leaves contain tannins, which are polyphenolic substances with molecular weight greater than 500. Tannins are hydrolyzed by enzymes, yielding sugar residues and phenol carboxylic acid. The latter compound can condense, forming polymeric flavoids (or condensed tannins).[50] The presence of condensed tannins in cassava leaves is of concern.[25] Tannins are able to form indigestible complexes with protein, thus increasing the amino acid requirements of animals fed diets containing cassava leaf meal. Tannin contents in cassava leaves are known to increase with maturity[8,51] and also vary between cultivars.[52] The reported values for tannins (3-5% dry matter basis) in cassava leaves, however, are comparable to those of most plant leaves, including alfalfa, and are within safe limits if judiciously used for animal feeding.

**Harvesting**

The appropriate harvesting method under the current practice of small-scale cassava production is to manually harvest the foliage by stem-pruning. The foliage, including tender stems can be wilted, green-chopped and used directly for ruminant feeding. Alternatively leaves can be stripped, dried and ground into a meal. The development of a mechanical harvesting device is desirable for large scale foliage production.

**Processing**

The presence of cyanogenic glucosides has made some form of processing a pre-requisite for the use of cassava leaves in animal feeding. Several studies have demonstrated that it is possible to produce cassava leaf meal with low cyanide levels.[51, 53, 54, 55] Sun-drying alone eliminates almost 90% of the initial cyanide content. When combined with chopping and wilting, cyanide in the dried meal was reduced to levels which are safer for monogastric animals (Table 4). This reduction is due to the action of endogenous linamarase on glucosides following loss of cell integrity (wilting) or tissue damage (chopping).

**Table 4: Hydrocyanic acid content[a] of cassava leaf meal as influenced by processing methods.[b]**

| Wilting (days) | Sun-drying | |
|---|---|---|
| | Full leaves[c] | Chopped leaves[d] |
| 0 | 173 (88.0)[e] | 109 (92.4) |
| 1 | 141 (90.2) | 88 (93.4) |
| 2 | 114 (92.1) | 72 (95.0) |
| 3 | 93 (93.5) | 53 (96.3) |

[a] mg/kg dry matter.

[b] Ravindran et al.[53]

[c] Freshly harvested cassava leaves contained an average of 1436 mg HCN/kg dry matter.

[d] Freshly chopped cassava leaves contained an average of 1045 mg HCN/kg dry matter.

[e] Values in parantheses represent the reduction in HCN as a percentage of initial level in freshly harvested leaves.

Free tannin contents of cassava leaves are also markedly lowered by drying.[52] Similar reductions during drying have been reported for *Leucaena* leaf meal.[56] It appears that drying irreversibly fixes tannins to other cell polymers,[50] thereby reducing the total assayable tannin content.

From a practical point of view, sun-drying is the method of choice in tropical countries. Since sundrying is entirely dependent on the weather, the duration of drying will vary considerably. In general, cassava leaves dry easily and drying to about 10-12% moisture content is completed in two days during dry sunny weather. For large scale production artificial heat-drying will be preferred since it becomes independent of weather, but the capital investment will be higher. It is noteworthy that artificial drying is less effective in eliminating the cyanide than sundrying[51] due probably to the shorter duration of drying.

An effective and simple procedure of processing cassava leaf meal is outlined below.

1. Chopping - Leaves can be chopped manually or by means of a mechanical chopper. Leaves may also be bruised instead of chopping. Chopping not only increases cyanide elimination, but also shortens the drying time.

2. Wilting - Leaves can be wilted by spreading out in shade or in a room with cross-ventilation. The duration may vary from few hours to few days. Leaves should be turned over regularly to avoid fermentation and mould formation. Wilting is a necessary step for the removal of cyanide from cassava leaves.

3. Drying - Wilted leaves should be uniformly spread on the floor and turned over as necessary.

   Once moisture level of 12% is reached, the leaves can be preserved either in the form of leaf meal or pellets. Pelleting in the absence of steam results in some maillard products and mild damage to the protein, which exhibits lower solubility. This is beneficial to ruminants but not to monogastric animals. Therefore, leaf meal is more suitable for poultry and pigs; pellets are more suitable for ruminants. Processing has little influence on the crude protein content of the leaf meal. Chopping of leaves however, has been reported to cause slight reduction in the protein content.[53]

**Storage**

Preliminary investigations indicate that cassava leaf meal has excellent storage qualities. There is no moulding or insect infestation even after 8 months of storage. Interestingly, the cyanide content declines during storage, but a gradual decline in the crude protein content was also observed (Table 5). It is expected that pigmenting carotenoid levels will fall during storage[56] but data relating to cassava leaves are not available.

**Table 5: Hydrocyanic acid and crude protein contents of cassava leaf meal as influenced by storage time.**

| Storage time (months) | Crude protein content (%) | HCN Content (mg/kg) |
|---|---|---|
| 0 | 22.7 | 91 |
| 2 | 22.6 | 68 |
| 4 | 21.7 | 49 |
| 6 | 20.9 | 40 |
| 8 | 20.3 | 38 |

[a]Ravindran et al.[53]

**Feeding Value for Poultry**

At low levels of inclusion, the feeding value of cassava leaf meal for poultry is similar to that of dehydrated alfalfa meal. Ravindran *et al.*[57] compared the performance of quails fed isonitrogenous diets containing 0, 2.5, 5.0, 7.5 and 10.0% levels of either cassava leaf meal or dehydrated alfalfa meal. Gains were not significantly influenced by the level of leaf meal inclusion, but feed intake and feed/gain were linearly increased as leaf meal were incorporated above the 5% level. The performance of birds fed cassava leaf meal and dehydrated alfalfa meal were similar.

Ross and Enriquez,[58] in a series of trials, investigated the possible use of cassava leaf meal in corn-soybean meal diets for chicks. Progressive depression in performance was observed with increasing levels of cassava leaf meal. However, supplementation of diets containing 20% cassava leaf meal with methionine and energy resulted in performance comparable to controls (Table 6).

**Table 6: Effect of methionine and/or soybean oil supplementation on the performance of White Leghorn Cockerels fed diets containing 20% cassava leaf meal.[58]**

| | Body weight (g) | Feed/gain |
|---|---|---|
| Control (Corn/soybean meal) | $219^{a}$ | 1.86 |
| 20% Cassava leaf meal | | |
| + 0.15% methionine | $177^{b}$ | 2.11 |
| + 0.20% methionine | $191^{ab}$ | 2.06 |
| + 3.0% soybean oil | $140^{c}$ | 2.45 |
| + 0.15% methionine and 3.0% soybean oil | $192^{ab}$ | 2.06 |
| + 0.20% methionine and 3.0% soybean oil | $212^{a}$ | 2.14 |

a, b, c, Means in the same column with different superscripts are significantly different ($P < 0.05$).

Montilla *et al.*[59] reported depression in gains and feed efficiency when cassava leaf meal was included at 10,20 or 30% levels in broiler rations. Cassava leaf meal was used to replace parts of the cotton seed meal, sesame meal and corn in the basal ration. The depressing effects due to the inclusion of cassava leaf meal were largely overcome by pelleting. Montilla[60] concluded that cassava leaf meal can be incorporated up to 20% level in pelleted broiler rations.

Wyllie and Chamanga[61] found cassava leaf meal to be a superior substitute for cotton seed meal in broiler rations. Replacement of cotton seed meal with 5 and 10% cassava leaf meal resulted in significant improvements in gains. However, when cassava leaf meal was substituted for sesame meal and sunflower meal, the performance of broilers was poorer.

Several workers have evaluated cassava leaf meal as a substitute for coconut meal and concluded that up to 10-20% level can be used with satisfactory results.[54,55,62] Broiler performance was depressed at levels of more than 20%. Evidence suggests that cassava leaf meal may be better utilized by older birds. Cassava leaf meal, as a replacement of coconut meal, can be included in layer diets up to 25% level without adverse effects on egg production, egg quality or feed efficiency.[63,64] The ability of layers to better utilize cassava leaf meal may be related to their greater tolerance to low-energy diets[65] and cyanide.[66]

The reported values of metabolizable energy of cassava leaf meal for poultry range from 1.59 kcal/g[67] to about 1.90 kcal/g.[54] Ravindran *et al.*[23] determined the true metabolizable energy for poultry to be 1.93 kcal/g. These energy values are higher than those reported for alfalfa leaf meal[68] and *Leucaena* leaf meal.[56]

The available data show that cassava leaf meal can be used as a poultry feed ingredient. Poultry producers in the tropics could benefit economically by incorporating low levels of cassava leaf meal. It can play useful role as a source of minerals,[15] xanthophylls[62,69] and unidentified growth factors[57] for poultry. The unfavourable effects of high dietary levels of cassava leaf meal are due to bulkiness, reduced energy intake and methionine deficiency. The roles of methionine as a methyl donor in tannin detoxification and as a source of labile sulphur in cyanide detoxification further aggravates its inherent deficiency in cassava leaf meal. At high levels of inclusion, bulkiness is probably the major limiting factor[62] and in this context, pelleting may prove beneficial.

**Feeding Value for Swine**

Limited published information exist regarding the use of cassava leaf meal in swine feeding.[70,71] Early studies of feeding fresh cassava leaves showed that palatability was depressed and growth performance was lowered with increasing proportions of leaves in swine rations.[72] The adverse effects were evidently due to the high hydrocyanic acid levels in fresh leaves, since supplemental methionine and thiosulphate improved performance.[73]

Sarwat *et al.*[74] found that inclusion of 15% fresh cassava leaves had no adverse effects on the performance of growing - finishing swine. Ravindran *et al.*[75] evaluated cassava leaf meal as a substitute for coconut meal. The results showed that properly processed cassava leaf meal can replace up to 66 per cent of coconut meal (26 percent of the total diet) in growing swine diets without adversely affecting performance. Maximum gains were obtained at 33 per cent replacement (13 per cent of the total diet), suggesting that use of low levels of cassava leaf meal in feed formulations will permit greater savings in feed cost compared to higher levels. The findings also indicated that cassava leaf protein is utilized efficiently, although other nutrients in cassava leaf meal are not as digestible as those in coconut meal. Studies of Rajaguru *et al.*[76] showed that cassava leaf meal can be used to substitute up to 20% of coconut meal in swine diets.

Attempts to utilize cassava leaf meal as a replacement for other protein supplements in swine diets have been less encouraging. Alhassan and Odoi[77] reported depressions in gains and feed efficiency when cassava leaf meal was included at 20 and 30% levels in diets for growing - finishing swine. Cassava leaf meal was used to replace part of peanut meal, fish meal and corn in the basal ration. The adverse effects appear to be partly related to the high levels of residual cyanide in the meal. The results emphasize the importance of proper processing of cassava leaf meal.

Ravindran[78] substituted 10,20 and 30% cassava leaf meal for a corn - soybean meal basal diet, and reported that gains and feed efficiency of growing pigs were lowered linearly with increasing levels of leaf meal. The performance of pigs on diets containing 10% cassava leaf meal was improved by methionine and energy supplementation (Table 7). There is unexplored potential for the use of cassava leaf meal as a source of protein in breeder diets. It is well known that energy in fibrous feedstuffs, such alfalfa meal, is well utilized by sows.[79,80]

**Table 7: Effect of feeding corn-soybean meal diets containing graded levels of cassava leaf meal (CLM), and of methionine and coconut oil supplementation on the performance of growing pigs.[78]**

| | Daily gain (kg) | Feed/gain |
|---|---|---|
| Trial 1 | | |
| Control (corn/soybean meal) | 0.56$^a$ | 2.7$^a$ |
| 10% CLM | 0.48$^b$ | 3.1$^b$ |
| 20% CLM | 0.42$^c$ | 3.6$^c$ |
| 30% CLM | 0.37$^d$ | 4.0$^d$ |
| Trial 2 | | |
| Control (corn/soybean meal) | 0.54$^a$ | 2.6$^a$ |
| 10% CLM | 0.46$^b$ | 3.1$^b$ |
| 10% CLM + 0.2% methionine | 0.48$^b$ | 3.0$^b$ |
| 10% CLM + 0.2% methionine + 1.5% coconut oil | 0.53$^a$ | 2.6$^a$ |

**[a,b,c,d] Within each trial, means in the same column bearing different superscripts differ significantly ($P < 0.05$).**

**Feeding Value for Rabbits**

Fresh cassava leaves, after some wilting, may be fed in restricted amounts to rabbits. Caution must be exercised because of possible cyanide toxicity. Processed cassava leaf meal can be included up to a level of 40% in compounded diets for rabbits without any adverse effects on performance.[81]

**Use of Cassava Forage in Ruminant Feeding**

The low nutritive value of tropical grasses and roughages, commonly available for use in ruminant production systems in the tropics, highlights the need for low-cost supplementation to improve animal productivity. In this context, tree legumes such as *Leucaena, gliricidia* and *Sesbania* are being promoted as protein supplements for livestock. Surprisingly, despite its availability and high protein content, there was little interest until recently in utilizing fresh cassava forage in ruminant feeding. This reluctance is probably related to possibilities of cyanide toxicity. Today it is no longer necessary to make a case for the supplemental protein value of cassava foliage. An abundance of published data is available on this.[82-87]

Fresh cassava foliage is a satisfactory protein supplement, but it should be wilted before feeding and prudently used for good results. Wilting not only lowers potential cyanide toxicity, but also reduces the free tannin levels and improves its acceptability to animals. The supplement value of cassava foliage is comparable to those reported for tropical tree legumes.[84] No adverse effects on performance have been reported even when higher levels of wilted cassava foliage were offered to goats and sheep (Table 8).

**Table 8: Intake and growth response of small ruminants receiving napier grass to cassava leaf supplementation.[84]**

| Supplement | Intake/kg $BW^{0.75}$ | | Average daily gain (g) |
|---|---|---|---|
| | Digestible dry matter (g/day) | Crude protein (g/day) | |
| Lambs | | | |
| None | 47 | 10 | 35 |
| Cassava leaf *ad lib.* | 49 | 13 | 44 |
| Goats | | | |
| None | 42 | 6 | -2 |
| 500 g cassava leaf | 43 | 7 | 13 |
| 1000 g cassava leaf | 46 | 9 | 21 |
| 1500 g cassava leaf | 54 | 9 | 23 |

Cassava foliage can be satisfactorily preserved as a silage[86,88] and then be used as a dry season feed. Inclusion of cassava foliage with roughage improves fermentation and increases the protein content of the silage. However, energy utilization of the silage was lower than that of cassava foliage hay.[88]

**Cassava Leaf Protein Concentrate**

Although the potential for the use of cassava leaves in the feeding of monogastric animals is enormous, factors such as high fibre and cyanide contents limit its use as a major source of protein. These limitations could be largely overcome if the protein is separated from the fibre and a protein concentrate is prepared by a juice extraction step and steam coagulation. Leaf protein concentrate (LPC) has been prepared from cassava leaves by a number of researchers.[89-93] Byers,[89] who studied leaves from 60 tropical plants in Ghana, found that protein was poorly extracted from the cassava leaf. Similarly, Singh[92] in India and Kling *et al.*[94] in Brazil reported poor extraction from cassava leaves. Because of the poor extraction, Telek and Martin[95] were of the opinion that cassava had no potential for LPC production. In contrast, studies from Nigeria show that cassava leaf protein has a reasonably good extractability. An extractability of 70% was obtained by Oke.[96] Fafunso and Oke[90] extracted leaf protein from 15 cultivars of cassava. All cultivars had similar extractabilities, with an average of 59%. Tupynamba and Vieira[93] reported a variability in extraction ranging from 20.2 to 64.7% The reported inconsistency in the extractability of cassava leaf protein may be related, at least in part, to different extraction techniques. Clearly further research is needed to develop refined technology to improve the protein extraction from cassava leaves. Tupynamba and Vieira[93] reported that cassava LPC, on an average, contained 46.1% crude protein, 3.5% crude fibre, 2.9% ash, 19.8% ether extract and 28.6% nitrogen free extracts. Over 75% of the protein was true protein and the papain digestibility of cassava LPC ranged from 52.8 to 60.9%.[90] The amino acid content of cassava LPC is superior to that of oil seed meals and comparable to that of animal protein supplements, with the exception of sulphur containing amino acids.[70,93]

The production of LPC also overcomes the problem of cyanide in cassava leaves. Very little cyanide remains in the protein concentrate[91,96,97], with 75% of the cyanide in fresh leaves being lost during pulping and pressing. The remaining cyanide in the wet-leaf fraction is largely eliminated during drying.

Despite its low cyanide content and good amino acid profile, nutritional evaluation of cassava LPC has shown poor animal performance.[98] Tupynamba and Vieira[93] reported that rats fed on diets containing cassava LPC lost weight, resulting in a negative PER value. The rats responded to supplemental methionine, but the PER value remained low, 0.28 as against 2.97 for those fed on the casein diet. The apparent digestibility of cassava LPC has been shown to be only 50%.[99] The low digestibility along with the presence of tanninmay be responsible for the poor nutritive value of cassava LPC. Studies with poultry, however, indicate that cassava LPC can be used satisfactorily as a source of protein for chicks. In fact, Cassava LPC was shown to be a more effective protein source than fish meal.[100] The fibrous residue that remains after leaf protein extraction can still be used as a feed for ruminants.[101]

**Conclusions**

It is clear from the foregoing discussion that the nutritional potential of cassava leaf outweigh possible limitations by their anti-nutritional factors. The technical feasibility of preparing and utilizing cassava leaves for animal feeding has now been amply demonstrated. The most immediate prospects for their use are in the following areas:

1. Low level (5-10%) inclusion of cassava leaf meal in poultry and swine formulations.

During the next decade, rapidly increasing prices of feed protein sources will make feed compounders in the tropics to reconsider their basic feed formulations. It is in this light that cassava leaf meal may find its use. The type of ingredients generally used in tropical countries are very diverse and cassava leaf meal can be easily accepted into this diversity. It can be developed into a green feed with all the impact of alfalfa meal in temperate countries. A process for the preparation of cassava leaf meal on a commercial scale has been outlined by Muller.[102] With experience, the use of moderately high levels of cassava leaf meal may be particularly considered in layer and pig breeder rations. Due to overpigmentation of the carcass, use of higher level of cassava leaf meal in broiler and pig finisher rations should be avoided.

2. Cassava forage as a supplement to low-quality roughage in ruminant feeding. Cassava foliage is emerging as a valuable protein supplement to ruminants feed on low-quality roughage. It can be safely utilized with beneficial effects on animal performance.

It can be stated that today's knowledge of cassava leaves is equivalent to what was known about the alfalfa about 60 years ago. Many, if not most, of the advances made with regard to alfalfa utilization may have similar applications to cassava leaves. The task ahead is to solve the limitations, both biological and economical, that will allow the development of an acceptable system of cassava leaf production. In this context, the following research needs are emphasized; (i) breeding or selection of cassava varieties which can be grown specifically for foliage production.[103] The characters to be considered *inter alia* are forage yields, protein content, cyanide content, tannin content and ease of harvesting, (ii) suitable agronomic practices to obtain high yields of forage with better nutritive value, (iii) development of appropriate technology for the processing of cassava leaf meal and pellets, (iv) studies on the effects of processing on the feed value of cassava leaf meal, (v) possibility of using cassava leaf products in combination with the enerty-rich roots, (vi) study of the economics of cassava grown only for leaf production and for production of cassava root/leaf combination and (vii) study of market prospects for cassava leaf products.

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