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Organisation de Coopération et de Développement Économiques
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English - Or. English

ENVIRONMENT DIRECTORATE
JOINT MEETING OF THE CHEMICALS COMMITTEE AND
THE WORKING PARTY ON CHEMICALS, PESTICIDES AND BIOTECHNOLOGY

ENV/JM/FOOD(2006)6/REV3
For Official Use

Task Force for the Safety of Novel Foods and Feeds

CONSENSUS DOCUMENT ON COMPOSITIONAL CONSIDERATIONS FOR NEW VARIETIES OF CASSAVA (Manihot esculenta Crantz): KEY FOOD AND FEED NUTRIENTS, ANTI-NUTRIENTS, TOXICANTS AND ALLERGENS

15th Meeting of the Task Force for the Safety of Novel Foods and Feeds,
to be held in Paris, France, 10-12 February 2009

English - Or. English

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At the 10th Meeting of the Task Force for the Safety of Novel Foods and Feeds (June 2005), South Africa presented a proposal to produce a consensus document on Cassava (*Manihot esculenta* Crantz) [ENV/JM/FOOD(2005)4/ADD1]. A revised outline of the Table of Contents was submitted for discussion at the 11th Meeting.

The first draft *Consensus document on Compositional Considerations for New Varieties of Cassava: Key Food nutrients, Anti-nutrients and Toxicants* [ENV/JM/FOOD(2006)6] was prepared by the lead country, South Africa, for presentation at the 12th meeting of the Task Force held in Greece in September 2006. Canada offered to co-lead with South Africa in the drafting of subsequent drafts. The document received a number of comments and a first revision was submitted to the 13th meeting (Paris, June 2007), followed by a second revision examined by the 14th Meeting (Paris, April 2008).

Since the last meeting of the Task Force, delegations from Australia, Canada, United States and Brazil submitted their written inputs which were made available on the password-protected website. Then the two co-lead countries, assisted by experts from Australia, Brazil, Clayuca-CIAT Colombia, IITA Nigeria and the United States, took them into consideration to draft the present third revision, completed with some editorial inputs from the OECD Secretariat. The document [ENV/JM/FOOD(2006)6/**REV3**] will be presented to the 15th Meeting of the Task Force.

Section VI – References still needs be completed. An Addendum [ENV/JM/FOOD(2006)6/REV3/ADD1] will be circulated later.

ACTION REQUIRED: The Task Force is invited to:

a) ***examine this document and suggest final editorial improvements where appropriate; and***

b) ***agree that the document be forwarded to the Joint Meeting for declassification, amended as appropriate.***

Consensus Document on Compositional Considerations for New Varieties of Cassava [*Manihot esculenta* Crantz]: Key Food and Feed Nutrients, Anti-nutrients, Toxicants and Allergens

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ABOUT THE OECD

FOREWORD

PREAMBLE

THE ROLE OF COMPARATIVE APPROACH AS PART OF A SAFETY ASSESSMENT

[These four sections will be completed by the OECD Secretariat later on when circulating the document to the Joint Meeting for declassification. Updated texts can be found in Consensus Document No.17 on Tomato issued in October 2008 [ENV/JM/MONO(2008)26], available on the public Website at: http://www.oecd.org/document/9/0,3343,en_2649_34391_1812041_1_1_1_1,00.html .

TABLE OF CONTENTS

Tables

Figures

ACRONYMS

CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)
CLAYUCA	Consorcio Latinoamericano y del Caribe de Apoyo a la Investigación y al Desarrollo de la Yuca (Latin American and Caribbean Consortium to Support Cassava Research and Development, hosted by CIAT)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Agricultural Research Corporation)
FAO	Food and Agricultural Organization of the United Nations
IITA	International Institute of Tropical Agriculture
USDA	United States Department of Agriculture

SECTION I – BACKGROUND

A. General description of cassava

1. Wild cassava (*Manihot flabellifolia* Phol and *Manihot peruviana*) is native to tropical America (Olsen & Schaal, 2001; Chacon *et al*., 2008). Cultivated cassava is known scientifically as *Manihot esculenta* Crantz. Cultivated cassava (referred to in this document as cassava) is also known amongst rural populations in various countries as yuca, manioc and mandioca (see UNECE Website). It was later introduced to Africa and Asia, where it forms the subsistence base of the poorer populations in the marginal areas of these continents. Recently, Chacon *et al.,* (2008) came up with evidence suggesting that the subspecies of *M. esculenta* are not monophyletic, most probably due to hybridizations between the cultivated crop and wild species.

2. Cassava is a perennial woody shrub that produces storage roots within six months to three years. It is propagated by mature woody stem cuttings, while seeds are used mainly in the breeding program (El-Sharkawy, 2004). Under optimal environmental conditions it compares favourably in the production of energy with most other major staple crops due to its high yield potential (El-Sharkawy, 2004). The cultivars are traditionally characterized as high or low cyanide content. They can also be grouped into high and low starch varieties for commercial application, edible lines for human consumption, and lines suitable for animal feed. The leaves of cultivated cassava and wild *Manihot* possess elevated activities of PEP carboxylase but lack the Crantz anatomy of typical C4 species. An introduction on the biology of cassava is included in Appendix of the present document.

B. Production

3. Cassava is the fourth most important crop grown in the developing world (FAO, 2000; 2008). Sweet cassava cultivars, which contain low cyanogenic glucoside levels, are used for human consumption, while bitter cultivars are used for industrial purposes (FAO, 2000). Based on kcal per capita per day consumption, cassava ranks eighth among the major food crops, after rice, wheat, sugar cane, maize, soybean, potatoes and palm oil (FAOSTAT, 2008). Cassava is the staple food of nearly a billion people in 105 countries, where the cassava root provides as much as a third of daily calories. The roots are an important source of carbohydrates and the leaves are a source of proteins and minerals (FAO, 2000). Young cassava shoots (young stem, leaves and petioles) are also edible, are widely used as food in Africa, and constitute a major component of the diet in the cassava growing regions (Hahn, 1992; Achidi *et al*., 2001).

4. Cassava is produced mainly by small stakeholders in the humid and sub-humid tropics of Asia, Latin America and the Caribbean, and Africa, where cassava can grow and produce dependable yields on marginal or sub-marginal land that does not support the production of cereals or other crops (FAO, 2000; 2008). Historically, cassava has been used as a famine reserve and food security crop for resource-poor farmers because of its ability to grow on nutrient poor soil, to tolerate drought, to adapt to flexible planting and harvest times, and to produce carbohydrate efficiently (FAO, 2000).

5. Globally, production of cassava is expected to increase by over 50% during the period from 1993 to 2020 (Scott *et al*., 2000). World cassava production has increased from 189.9 Mt to 225.4 Mt during the period from 2002 to 2007 (Table 1). The five countries with the highest annual production of cassava are

Nigeria (45.8 Mt), Brazil (27.3 Mt), Thailand (26.4 Mt), Indonesia (19.6 Mt) and the Congo Democratic Republic (15 Mt) (FAOSTAT, 2008). Cassava production in Africa has grown at an average annual production growth rate of 3% over the past 40 years, and it is expected to double in the next twenty years (FAOSTAT 2006). Africa and Latin America and the Caribbean recorded similar increases in cassava production of about 15.7%, while in Asia production increased by 39.4%, from 51.5 Mt to 71.8 Mt, during the same period. Mozambique is the highest cassava producer in East Africa. The increase in global cassava production is not solely attributed to an increase in the area of cassava harvested (Table 2).

Table 1. Estimated global cassava production

Cassava production (Million tonnes- Mt)[a]	**Year**					
	1983-1985	**1993-1995**	**2000-2001**	**2002-2003**	**2004-2005**	**2006-2007**
Africa	55.3	83.2	98.8	103.4	112.5	118.0
Asia	47.9	49.2	51.1	53.6	57.6	69.5
Latin America and the Caribbean	28.5	31	31.7	32.6	35.9	37.7
Oceania	0.2	0.2	0.2	0.2	0.2	0.2
World	**132.0**	**163.5**	**181.8**	**189.9**	**207.4**	**225.4**

Source: FAOSTAT (2008)

[a] In comparing cassava production figures with those of grain crops, note that cassava production figures are reported at 70% moisture content, while most grain crops are reported at approximately 15 percent moisture content (FAO, 2000b).

6. World average yields of cassava increased from 9.3 t/ha to 12.2 t/ha during the period from 1983 to 2007 (FAOSTAT, 2008). In 2007, the world average yield of fresh cassava roots was 12.2 t/ha, with an average of 18.6 t/h in Asia, 10 t/ha in Latin America, and 9.9 t/ha in Africa. Cassava yield varies with the cultivar, season of planting, soil type, and fertility (FAO, 2000). The average cassava yields in 2000 were estimated to be barely 20% of those obtained under optimum conditions which can result in yields ranging from 25-40 t/ha (FAO, 2000). The introduction of high-yielding varieties, improved pest and disease control and better processing methods could increase cassava production in Africa by 150% (FAO, 2000).

Table 2. Estimated global cassava harvest area

Cassava harvest area (million hectares)	**Year**					
	1983-1985	**1993-1995**	**2000-2001**	**2002-2003**	**2004-2005**	**2006-2007**
Africa	7.75	10.18	10.98	11.42	11.79	11.91
Asia	3.74	3.80	3.45	3.42	3.48	3.77
Latin America and the Caribbean	25.69	26.17	25.48	25.51	29..46	28.57
Oceania	0.02	0.02	0.02	0.02	0.02	0.02
World	**13.85**	**16.62**	**16.99**	**17.41**	**18.23**	**18.55**

Source: FAOSTAT (2008)

C. International Trade

7. The FAO cassava market assessment (2003) ranked Thailand as the main exporter of cassava with most of products exported to Europe (Table 3). The world market for cassava starch and meal is limited, due to the abundance of substitutes. International trade in aggregate dry cassava products (also called tapioca) underwent a sharp contraction in 2002, falling by 19% to just under 6 Mt (in cassava pellet equivalent). Despite a slight increase in the volume traded in the form of flour and starch, which stood at 2.6 Mt (1.3 Mt in product weight), trade in chips and pellets fell by 33% to 4.5 Mt. Against the backdrop

of declining trade, a major shift in the structure of international trade occurred in 2001, when imports by the developing countries surpassed those by the developed countries, for the first time. Indeed, in 2002, developing countries in the Far East were the major destination for international trade flows in cassava, importing around 3.4 Mt in aggregate. Much of the contraction in global cassava trade was concentrated in the European Union (EU), for years the major destination of cassava shipments, which it principally imported from Thailand (the world's leading exporter) in the form of pellets for the feed industry under a low tariff rate preferential quota. In 2002, however, the EU imports declined sharply by 43% to 1.5 Mt, reflecting the loss of competitiveness of cassava feed products vis-à-vis domestically produced grains. International quotations for cassava products were on average higher in 2002 than in the previous year. A tightening of exportable supplies in Thailand and steadfast demand in the Far East, particularly China, were by and large, behind the strengthening of international prices.

Table 3. Cassava World Export Trade[1]

	2000	2001 prelim.	2002 f'cast.
World exports	**6.9**	**7.4**	**5.9**
Thailand	6.5	7.1	5.7
Indonesia	0.2	0.1	0.1
Others	0.2	0.2	0.1
World imports	**6.9**	**7.4**	**5.9**
EU[2]	3.7	2.7	1.5
China[3]	0.9	2.6	2.5
Indonesia	0.5	0.2	0.1
Japan	0.6	0.7	0.7
Korea Republic	0.1	0.2	0.1
Malaysia	0.2	0.2	0.2
U.S.A	0.1	0.1	0.1
Others	0.8	0.6	0.7

Source: FAO, (2003)

[1]In product weight of chips and pellets [2]Excluding trade between EU members [3]Including Taiwan province

D. Processing and Use

1. General

8. About 60% of cassava produced worldwide is used for human consumption, 33% goes to the animal food industry and 7% to the textile and food industries (Soccol, 1996). Cassava tubers are valued as an energy source in human and animal diets (Babu & Chatterjee, 1999) having a carbohydrate content of about 92% (dry weight), mainly in the form of starch (Oke, 1968). Cassava tubers are low in protein (Babu & Chatterjee, 1999). The leaves are also consumed and are a source of vitamins A, C, Fe, Ca and protein (Nweke *et al.*, 2002).

9. A limiting characteristic for human or animal consumption is the cyanogenic glycoside content of cassava (Kakes, 1990). Cyanide (HCN) is largely removed by the traditional processes of grating, fermenting, boiling or drying (Hahn, 1989). Cooking the roots slowly destroys the cyanogens (Nweke *et al.*, 2002). The cyanogenic potential, yield, and dry matter content of cassava roots, as well as the pasting properties, influence the safety, quantity and quality of processed foods and industrial products. Cassava products are rarely eaten on its own, but commonly in combination with relatively protein-rich food.

However, certain processing techniques may result in the reduction or enhancement of the protein, vitamin, or mineral contents of the cassava roots. Nutrients such as vitamin C are lost in processing and cooking (Berry, 1993).

10. Post harvest physiological deterioration often begins within 24-48 hours (Beeching *et.al.*, 1998), and therefore roots need to be consumed or processed shortly after harvesting. Physiochemical and functional properties of the storage root primarily determine the quality of cassava-based products.

11. In Asia, cassava is mainly used as animal feed or as a source of starch products for food as well as industrial uses. Cassava remains an important food crop in Indonesia where dried cassava chips or chunks, known as gaplek, is pounded into a flour and shaken on a bamboo screen with some water to produce granules, called tiwul, which are cooked together with rice as a staple extender. Fresh cassava root is cooked and consumed in Kerala state of India and in some areas of Vietnam, China, and the Philippines (Howeler, 2004).

12. In Brazil it is estimated that 80 % of the total cassava root production is designated for cassava flour, an average of 23 million tonnes. The lack of official statistics and the existence of small and informal producers cause a bias in the estimate of total production. The variability of the different types of cassava flour in Brazil is extremely large, making its commercialization very difficult, as there is yellow cassava flour in the North Region, and white cassava flour in the rest of the country. The consumption of fresh cassava traditionally occurs throughout the country. Nowadays cassava is frozen, fried or boiled (Embrapa Mandioca e Fruticultura Tropical, 2005) (see FAO News Website).

13. Of the total cassava production in Colombia, more than 90% is consumed as fresh cassava (boiled and/or fried for humans) and less than 10% is processed for animal feeding, or as industrial products (starches, flours, and snacks) (see Agrocadenas Website). Cassava flour can also be used as a substitute (15%) for wheat flour in baking (FAO News Website). The most important processed product of cassava is bitter starch, which is fermented starch. It has a composition of 96% carbohydrates on a dry basis, 3% proteins and 12% moisture. It is good for making bread, because it expands during baking. Bitter starch is very important in the snack industry to produce local products such as *pandebono* and *pandeyuca* (cheese breads), *rosquillas* (small, baked and crunchy doughnuts) and *besitos* (small, baked and crunchy puffs) (Agrocadenas Website).

14. Processing of cassava leaves does not have a significant effect on the majority of the compositional nutrients. In a study by Achidi (2003), cassava leaves of two varieties of *Manihot esculenta* Crantz were subjected to processing (heat-treated, pounded and cooked and crushed, ground and cooked) and compared for proximate composition, minerals, vitamins and anti-nutritional factors. The processing methods had no significant effect on ash, lipids, protein, fibre, total carbohydrate, carotene, Ca, Mg, potassium, sodium, phosphorus, copper, zinc, and manganese, but produced significant reduction in free sugars, ascorbic acid, thiamine, cyanogenic potential, and tannin levels. Ravindra *et al.* (1987) determined the crude protein content of cassava leaf meal (including petiole) after different periods of wilting, methods of drying, and chopping or not chopping. Processing methods had little influence on the crude protein content of leaf meal. However, chopping of leaves resulted in consistently reduced crude protein content. The mean crude protein level was 23.1 g/100 g dry matter.

15. Fasuyi (2005) studied the leaves of three genetically improved varieties of cassava plants that were harvested and subjected to different processing methods (sun-drying, oven-drying, steaming, shredding, steeping, and a combination of these methods). The protein and mineral content were found to be high, particularly Ca, Zn, Ni and K. This study suggested a high potential of cassava leaf as an unconventional protein resource for both humans and animals.

2. *Human food processing*

16. For human food consumption, cassava is mainly eaten as fresh processed roots, fermented roots, cassava flour-based products or cooked leaves. Traditionally, cassava roots and leaves are processed by a variety of methods into many different products, depending on local customs and preferences. Cassava processing involves a combination of activities, performed in stages. They include (i) peeling; (ii) chipping, crushing, milling, slicing or grating; (iii) dehydration by pressing, decanting, or drying in the sun or over a hearth; (iv) fermenting by soaking in water, heaping or stacking; (v) sedimentation; (vi) sieving; and (vii) cooking, boiling, toasting or steaming. The number of steps required and the sequence varies with the product being made. This sequence of activities also generates a wide range of intermediate products, which can be either sold or stored until the need arises for conversion into a final product. In addition, some of the processed products can be eaten without further cooking, while others require some extra preparation (Nweke 1992). The most commonly used processing methods are presented in Figure 1.

3. *Animal feed processing*

17. All cassava varieties can be used in animal feed, but it is necessary to process them because of the presence of cyanogenic glycosides. On hydrolysis of the cassava glycosides, linamarin, hydrocyanic acid is formed. A level of less than 100 g CN/ kg considered as acceptable in animal feed.

Cassava Ensiling

18. Cassava is an ideal alternate energy source for animal rearing. Because of poor post harvest life of the tubers, rapid processing is important (Padmaja, 2000). Silage can be produced from forage and from cassava roots. The moisture content has to be reduced when forage is used for silage production. Cassava silage is prepared from different sources according the formula in Table 4.

Table 4. Formula for silage from different sources

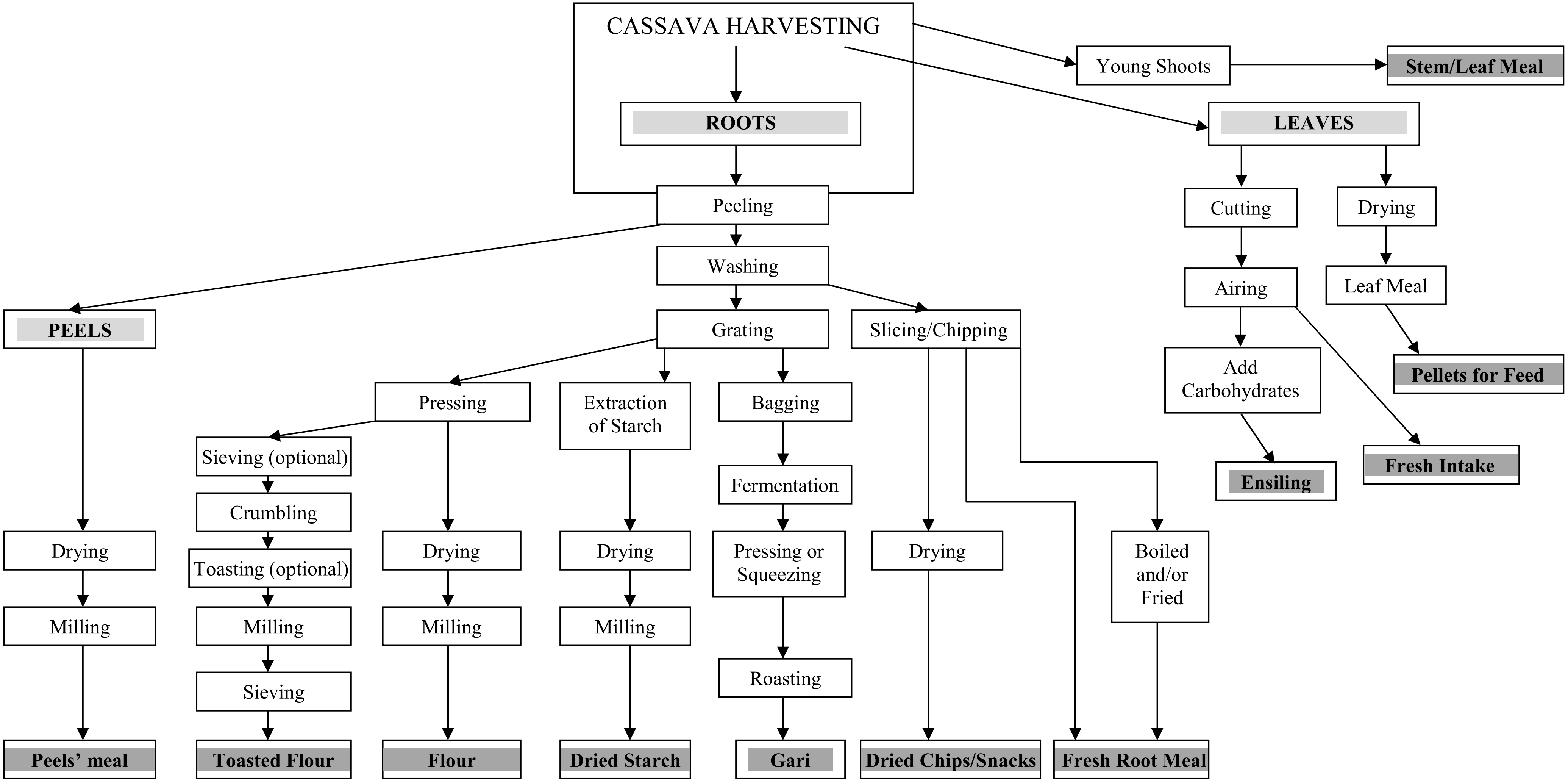
	Content (%)			
Forage	80.0	65.5	92.0	
Roots	20.0	33.0		98.2
Urea		1.5		1.8
Molasses			8.0	
Total	100.0	100.0	100.0	100.0

Source: Gil, 2004

Cassava Forage

19. In Colombia, as in some tropical countries, the aerial part of cassava can be used for animal feed, especially in ruminants. It is characterized by its high level of crude protein (22% on average). Cassava foliage provides pigmentation because it contains a considerable concentration of total xanthophylls (605 mg / kg) and xanthophylls (508 mg / kg) (Ceballos and Ospina, 2002).

Figure 1. Schematic representation of cassava processing into different food and feed products



F. Industrial Applications

1. Large range of industrial products

20. Industrial markets include those for unmodified starch for glucose products, food binders and thickeners for the paper and mining industries; and for animal feed. Modified starch can also be used widely in the food industry. Asia leads the way in terms of cassava starches. Cassava starch has unique properties such as high viscosity and resistance to freezing. There is great potential for cassava starch utilisation in Nigeria's wood, paper, textile, sweetener and alcoholic beverages industries, to name a few. These industries largely depend presently on imported starch. Development of cassava starch-based biodegradable plastics has huge potential. The starch industry is responsible for 3 % utilization of the cassava roots production in Brazil, and is a growing sector in the country.

2. Biofuel

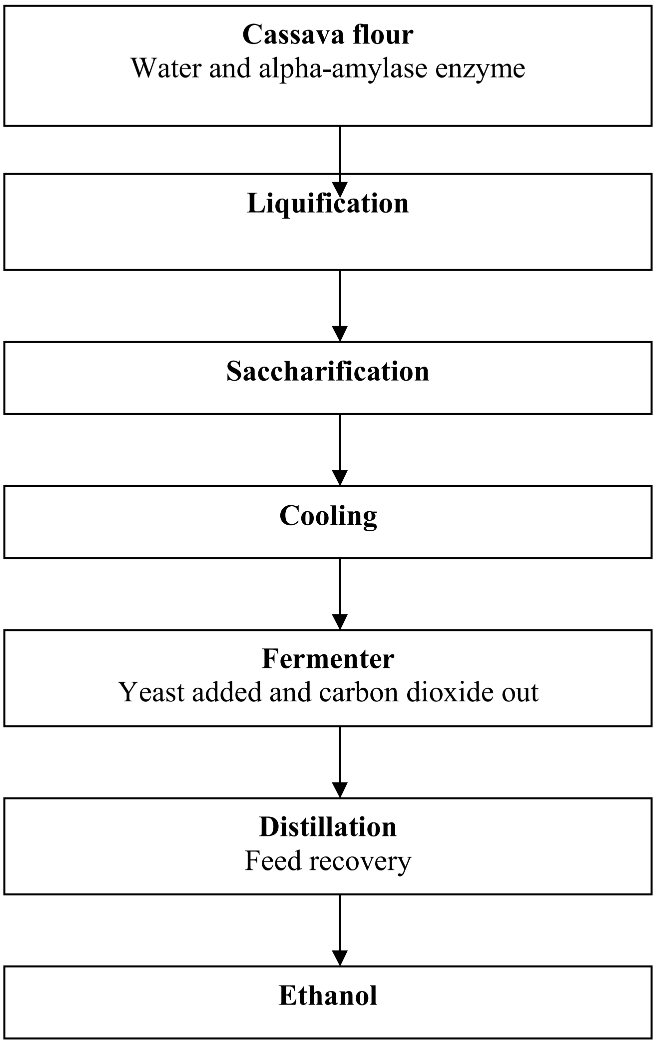
21. Apart from its traditional role as a food crop, cassava can be used as a carbohydrate source to produce ethanol, and has become an important biofuel crop in Brazil, Thailand, China and countries in Sub-Saharan Africa, especially Nigeria. The ethanol production process goes through a series of processes which produces sugar from starch (saccharification), and ethanol from sugar (fermentation).

22. A flowchart showing the process of ethanol from cassava starch is depicted in figure 2. Bioethanol can be used to substitute between 10% and 25% of petrol in vehicles with standard engines and up to 100% for adapted engines.

23. The high-energy cost and loss of fermentable glucose due to by-product formation necessitated the development of a low energy process to reduce the total manufacturing cost in the alcohol manufacturing process. A recent development is the use of granular starch hydrolyzing enzymes. Starch feedstock processing would become simpler, e.g., overall use of less energy, water, chemicals, labour, capital and higher yields of ethanol, robust operation, better animal feed and no waste. Novel granular starch hydrolyzing enzymes were developed which eliminated the need for a high energy, intensive jet cooking step for solubilizing and hydrolyzing the insoluble starch to fermentable sugars in the ethanol fermentation process (Shetty et al., 2005). Figure 3 is a schematic representation of processing granular starch feedstock to ethanol. This process has many advantages compared to the conventional dry milling process for fuel ethanol production. For example:

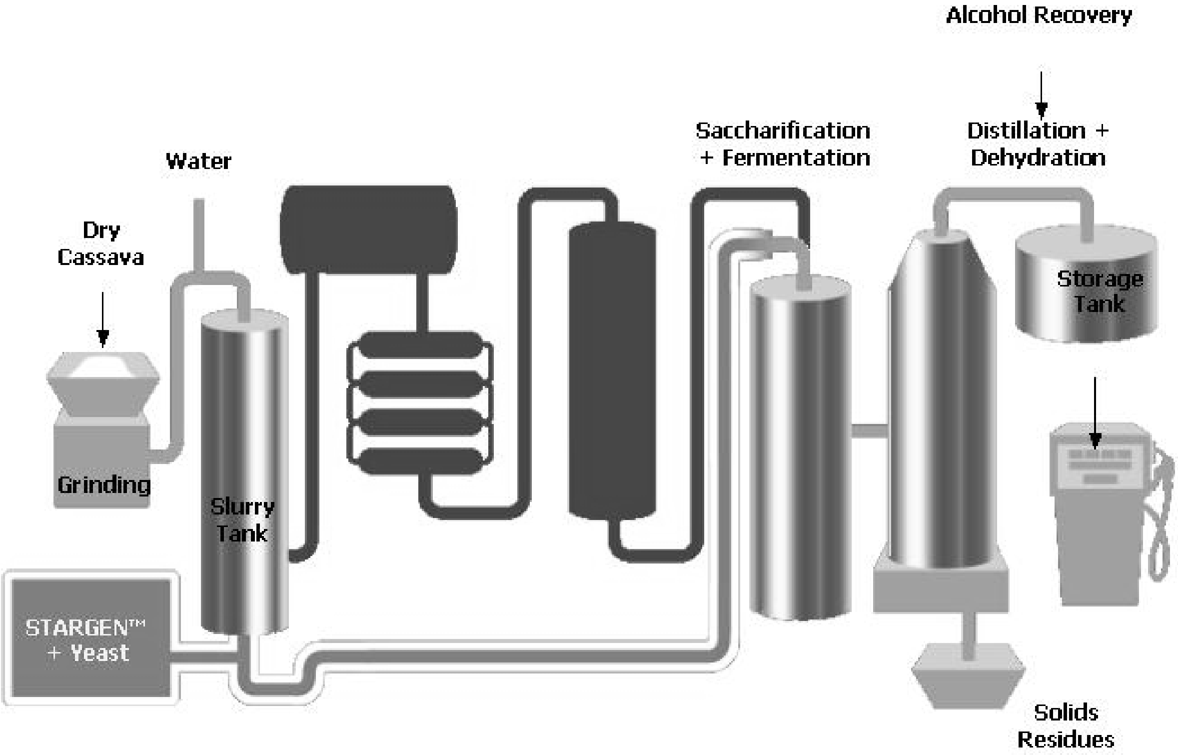
- Eliminates the need to finely grind the cassava chips;
- Eliminates jet cooking of starch;
- Reduces the cost of enzymes by providing the optimum conditions (temperature, pH);
- Reduces the risk of microbial contamination due to pre-treatment at 600C;
- Breaks down non-starch polysaccharides (fibre) to reduce fibre content in the co-product;
- Improves the potential for increasing plant throughput.

Figure 2. Schematic presentation of the cassava ethanol process



http://www.cassavabiz.org/postharveswt/ethanol101.htm (Dec 08)

Figure 3. Granular starch hydrolyzing enzymes in the ethanol production



D. Breeding characteristics screened by developers

24. The most important commercial quality trait for cassava breeders in Asia is starch yield. In Africa, breeders focus on disease and pest resistance (cassava mosaic disease; cassava brown streak; green mites; and bacterial blight). Other important objectives of cassava breeding are increased root protein content, β-carotene, and reduced cyanogenic levels. Cassava varieties exist that are either “bitter” or “sweet” in taste. Taste preferences are very much dependent on the local rural communities within countries. Since cassava is vegetatively propagated, and irregular flowering and low seed set occurs, breeding may not always be the appropriate choice for developing new varieties, and genetic engineering can provide an alternate means for developing improved or novel varieties (Taylor *et al.*, 2004). For example, the production of transgenic cyanogen-free cassava has already been achieved (Siritunga and Sayre, 2003), and a storage protein (ASP1) has been expressed in cassava (Zhang *et. al.*, 2003).

SECTION II – NUTRIENTS

25. The range of mean values for cassava roots and leaves as well as processed cassava products are shown in Tables 5 to 18.

A. Root, foliage and leaves

1. General

25. The nutrient composition of cultivated cassava varies between different reports. Observed differences are to some extent due to the genetic makeup of the crop. The composition of fresh cassava roots and leaves varies according to the age of the cultivated plant, and is also dependent upon where it is grown, cultivar or variety, climate and other agro-conditions (Fasuyi and Aletor, 2005). In a study by Nhu Phuc *et al.* (2000) of six cassava varieties from South Vietnam, India and Japan showed that cassava leaves varied substantially in composition, *viz.* (/100 g dry matter): 23.9 to 34.7 g crude protein, 13.3 to 15.6 g fat, 9.7 to 14.6 g crude fibre, 31.7 to 45.5 g nitrogen free extract and 5.0 to 7.9 g ash.

26. Representative data on nutrient composition of fresh cassava roots and leaves are presented in Tables 5 and 6, respectively. Variations in each of the parameters are indicated by the minimum and maximum values. A range of values are presented when they were available from the literature. In many reports where it was not stated whether the roots were peeled or not, it was assumed that they were not peeled. This would have a significant effect on composition, because of elevated fibre values in unpeeled roots. In unpeeled roots, root size will also affect proportion of fibre to non-fibre carbohydrate because small-unpeeled roots should contain proportionally more fibre that large roots. Also crude fibre and nitrogen-free extract analysis (Maynard *et al.*, 1979) have been replaced by neutral detergent fibre and acid detergent fibre analysis. However, only one author reported acid detergent fibre and neutral detergent fibre values.

27. Observed differences may also reflect to some extent the analytical method used, but to a large extent investigators used standard methods, such as those published by the Association of Official Analytical Chemists (AOAC, 1990).

Table 5. Nutrient composition of fresh cassava roots* (g/100 g dry matter)

References	**a**	**b USDA**	**c FAO**	**d**	**e**	**f**	**Range or Total**
Crude protein	4.7	2.1	1.9	2.0	2.4	1.5-3.5	1.5–4.7
Crude fibre	2.1	2.9	0.8	4.0		1.3-7.7	0.8-7.7
Crude fat [g]	2.5	0.4	0.3	0.7	2.2	0.8-3.2	0.3-3.2
Ash	8.4	1.0	0.5	5.0	1.5	1.6-4.1	0.5-8.4
NFE [h]	75.3	61.0	56.0	75.5		88.0-94.1	56.0-94.1
NDF [I]					5.5		5.5
ADF [j]					2.5		2.5

* Not always reported, but it is assumed the roots were not peeled.

a - Akinfala *et al.* (2002) Unpeeled roots
b - USDA (2005) National Nutrient Database. Release 18
c - FAO, 2007, http//www.fao.org/docrep/007/x3996p/x3996p18.htm
d - Oguntimein (1988)
e - Tien Dung *et al.* (2005)
f - Smith (1988)
g - Ether extractable fat
h - Nitrogen free extract
I - Neutral detergent fibre
j - Acid detergent fibre

Table 6. Nutrient composition of fresh cassava leaves (g/100 g dry matter)

References	a	b	c	d	e	Range or Total
Crude protein	18.0	23.9-34.7	24.1	14.7-36.4	20.0 -30.0.1	14.7-36.4
Crude fibre	14.1	9.7-14.6 11.5	26.0	4.8-15.4		4.8-26.0
Crude fat	9.4	13.3-15.6 14.3	5.0	4.0-15.2	5.9	4.0-15.6
Ash	7.9	5.0-7.9 6.5	8.0	5.5-16.1	10.0	5.0-16.1
NFE[f]	43.3	31.7-45.5 38.8	39.9	31.7-45.5	44.2	31.7-45.5
NDF[g]					29.6	29.6
ADF[h]					24.1	24.1

a - Akinfala *et al.* (2002) Composite sample prepared for trial
b - Nhu Phuc *et al.* (2000); 6 cultivars, sun-dried.
c - Oguntimein (1988)
d - Smith (1988)
e - Hang and Preston (2005) Leaves collected from upper part of plant at time of root harvesting
f - Nitrogen free extract
g - Neutral detergent fibre
h - Acid detergent fibre

28. The nutrient compositions of cassava foliage after three and six months are given in Table 7.

Table 7. Nutrient composition of cassava foliage after 3 and 12 months

Parameter	**Tender Foliage fresh basis**	**Tender Foliage (3 month) dry basis**	**Foliage of 12 month dry basis**
	(%)	**(%)**	**(%)**
Mixture	75.00	12.00	12.00
Crude protein	6.50	26.70	20.50
Ash	Sd	9.78	9.00
Fat	1.80	5.53	4.30
Crude fibre	4.70	19.63	25.50
P	0.09	0.39	-
Ca	0.52	1.70	-
K	0.34	2.28	-

Source: Gil, 2004

2. Proximate composition

Dry matter/moisture of roots and leaves

29. In general, a wide variation in moisture content of roots has been published. Using the specific gravity method, Chavez *et al.* (2005) measured the moisture content of 2,022 root samples collected from all over the world. The dry matter values ranged from 10.7 to 57.2 g/100 g fresh sample weight, with a mean of 34.3 g/100 g sample. Dry matter content is not presented in the following Tables 5 and 6 because, in most studies, no clear indication was given at what stage of the processing or harvesting the moisture determination was done.

30. Results from a study on young cassava leaves obtained from 19 cassava varieties, showed that the dry matter content of cassava leaves ranged from 23 to 27.8%. (Achidi, 2003), while Gomez & Valdivieso (1984) recorded dry matter values between 30.8 and 35.7 g/100 g in leaves (plus petioles) harvested at 9 to 12 months after planting.

Crude protein

31. Crude protein is widely determined using the Kjeldahl technique, in which the nitrogen content is measured and multiplied by 6.25 to get an estimate of crude protein. In more recent studies the Dumas method of measuring nitrogen has been used, which is a more accurate method of measuring nitrogen content in samples containing relatively high levels of non-protein, e.g. from HCN which is reported to be present in cassava roots.

32. However in cassava, and possibly other crops, not all the nitrogen is incorporated in proteins, while different germplasms and growth conditions create huge variations in free amino acids and non-protein nitrogen, NPN, (Yeoh and Truong, 1996). If the NPN content is subtracted from the total N (Kjeldahl method) or protein content measured by performing a spectrometric assay, it would appear that the protein content (by the Kjeldahl method) is overestimated by a factor of 4 to 6. Chavez *et al*., (2005) analysed the roots (assumed unpeeled) of 600 cassava genotypes collected world-wide and reported a mean crude protein content of 3.561 g/100 g dry matter, ranging from 7.75 to 8.31 g/100 g dry matter. Additional research (Ceballos *et al*., 2006) was conducted to identify varieties containing high protein levels. In this study, cassava roots were found with a crude protein content ranging between 0.95 and 6.42 % when a 5.31 conversion factor was used. HCN was also measured and correlated to crude protein content. It was concluded that there was no correlation between HCN content and crude protein content, as most of the HCN is removed from the plant in sample preparation. Fifteen cassava varieties from Asia showed root protein ranging from 0.5 to 1.9 g/100 g dry matter (Hock-Hin and Van-Den, 1996). The value of 6.42/100 g and 8.3/100 g in roots as shown in some landraces from South America is high, but most cassava cultivars have a lower level of crude protein in the roots (1.5 to 4.7 /100 g dry matter), while leaves exhibit a range between 14.7 to 36.4 g/100 g dry matter (Tables 5 and 6).

Crude fat

33. The crude fat was measured as ether extract. Cassava roots contain low concentrations of fat, ranging from 0.3 to 3.2 g/100 g dry matter (Table 5). However, the leaves contain relatively high levels of fat, ranging from 4.0 to 15.6 g/100 g dry matter (Table 6).

Nitrogen free extract

34. Nitrogen free extract (NFE) representing the non-fibre carbohydrates constitute a heterogeneous chemical group, and total NFE are usually determined by difference (moisture, fat, ash, crude fibre and proteins are measured and the remainder is NFE). NFE (including starch) levels in cassava roots vary considerably depending on the cultivar, ranging between 56 to 94 g/100 g dry matter (Table 5). However, whether the roots were peeled or not would have a significant effect on the proportion of non-fibre carbohydrates in the roots. Leaves contain lower levels of NFE than roots, ranging between 31.7 and 45.5 g/100 g dry matter (Table 6).

Ash

35. Ash is what remains after the organic part of the plant material has been oxidized through combustion, and is a measure of the total amount of inorganic components in the samples. For cassava roots, it varies between 0.5 and 8.4 g/100 g dry matter, while in leaves this is higher, ranging between 5 and 16.1 g/100 g dry matter (Tables 5 and 6). To what extent the variation is due to soil contamination is not clear, because in some references it was stated clearly that the roots were washed while in others no mention was made about the preparation of the material. Fresh leaves have an ash content of 10g/100g dry weight according to studies conducted by Eggum, 1970; and by Luyken *et a*l., 1961.

Acid Detergent Fibre and Neutral Detergent Fibre

36. As previously mentioned, ADF and NDF provide much more accurate fibre values for feeds containing high levels of lignin as part of the fibre, than the proximate analysis of crude fibre and NFE; however, only one author reported values for these parameters. ADF and NDF are strictly not grouped as proximate (Tables 5 and 6).

Carbohydrates

37. Cassava roots are a good source of energy, having a carbohydrate content of about 92%, mainly in the form of starch (Oke, 1968). High carbohydrate content of dry cassava roots has been confirmed by Sanchez *et al.* (in the press). The high starch content consisting of about 20% amylose and 70% amylopectin which makes for ideal digestion (Johnson and Raymond, 1965). The metabolisable energy varies with the age, time, country, method of processing, and the variety. Differences might also be due to the state of cassava, the raw sample having a digestibility of about 48.3% and the cooked 77.9%. In general, the metabolisable energy of cassava is about 92% that of maize, and its high amylopectin content relative to maize makes it a more suitable source of energy for ruminants than for monogastric animals (Oke, 1978). Analysing 1,755 samples, Chávez *et al.* (2005) recorded a total root sugar content of 8.4 g/100 g dry matter and that of reducing sugars, 2.2 g/100 g dry matter. Szylit *et al.* (1978) determined that cassava roots contain 74.7 g starch/100 g dry matter and 0.6 g ethanol-soluble carbohydrates/100 g dry matter and a mean starch granule diameter of 12 µg. Cassava starch is classified as easily degradable, since 20% degraded in 6 hours when exposed to bacterial α-amylase *in vitro* (Szylit *et al.*, 1978).

38. In study by Nhu Phuc *et al,.* (2000) of six cassava varieties from South Vietnam, India and Japan showed that cassava leaves varied substantially in composition. In leaves, free sugars range from 2.2 to 4.4 g/100 g dry matter, starch from 4.7 to 6.1 g/100 g dry matter, total non-fibre carbohydrates from 7.1 to 10.4 g/ 100 g and food energy from 307.0 to 376.2 x 10^3 joules/kg dry matter.

Crude fibre

39. Cassava normally contains more crude fibre (0.8 -7.7 g/100 g dry weight and ash (0.5 -8.4 g/100 g dry weight) than maize and this decreases its digestibility. Crude fibre and ash content is highly dependent on growth conditions and germplasm of cassava. Cassava bagasse (solid waste from industrial processing) is a fibrous residue which contains 14.88–50.55 g of crude fibre/100 g dry weight and can be used in bioconversion processes using microbial cultures (Pandey *et al.*, 2000). Digestibility is important in cassava-based diets, for both humans and animals. Excess fibres interfere with the utilization of phosphorous and zinc (Oke, 1978). Fresh leaves have a high fibre content (average of 17g /100 g dry weight but digestibility is low (70-80% in young leaves and decreasing to 67% in old leaves) (Eggum, 1970; Luyken *et a*l., 1961).

3. True protein (amino acids)

40. Cassava roots contain so little protein (0.7 to 2%) that the amino acid composition is of little significance in nutrition. Of the small amount of nitrogen in cassava roots, only about 60% is protein nitrogen, while 30 to 40% is non-protein nitrogen, comprising of free amino acids, nitrate, nitrite and cyanide. The crude protein (Kjeldahl-N) of 15 varieties of cassava roots analysed by Yeoh & Truong (1996) contained 51.5% true protein. The authors estimated that 51 to 75% of the nitrogen in cassava roots consists of true protein, i.e. protein-amino acids.

41. The amino acid composition of the true protein in cassava roots, as well as the concentration of individual amino acids per 100 g dry matter, is presented in Table 8. However, the latter will depend on the concentration of true protein per 100 g dry matter. In Table 6 the mean values in the two studies reported were 0.404 and 0.827 g/100 g dry matter, while that of the individual cultivars analysed by Nassar & de Sousa (2007) varied between 0.255 and 1.654 g/100 g dry matter.

Table 8. Amino Acid composition in the protein of cassava roots (g/ 100 g dry matter)

References		**A**	**b**	**c**	**Range**
EAA [dc]	**Arginine**	0.145	0.178	0.230	0.145-0.230
	Histidine	0.020	0.034	0.034	0.020-0.034
	Isoleucine	0.031	0.046	0.045	0.031-0.046
	Leucine	0.055	0.064	0.065	0.055-0.065
	Lysine	0.043	0.067	0.074	0.043-0.074
	Methionine	0.019	0.022	0.018	0.019-0.022
	Phenylalanine	0.065	0.041	0.044	0.041-0.065
	Threonine	0.030	0.043	0.047	0.030-0.047
	Tryptophan	-	0.019	0.032	0.019-0.032
	Valine	0.056	0.054	0.059	0.054-0.059
NEAA [e]	**Alanine**	0.048		0.064	0.048-0.064
	Aspartic acid	0.068		0.132	0.068-0.132
	Cystine	0.026	0.023	0.047	0.0230-0.047
	Glutamic acid	0.124		0.345	0.124-0.345
	Glycine	0.038		0.047	0.038-0.047
	Proline	0.020		0.055	0.020-0.055
	Serine	0.040		0.055	0.040-0.055
	Tyrosine	0		0.028	0.00 – 0.028
	AA/100 g dry matter	0.827	0.404	0.773	0.404-0.827

a - Nassar and de Sousa (2007)
b - Oke (1978)
c – USDA (2008)
d – Essential amino acids for a rat
e– Non-essential amino acids for a rat

42. Nhu Phuc *et al.* (2000) analyzed six cassava varieties from South Vietnam, India and Japan for their amino acid profile, to determine protein quality. The results indicate that, on average, the amino acids glutamic acid and leucine were highest, with values above 4 g/100 g true protein, followed by aspartic acid, arginine, and alanine with values above 3 g/100 g true protein.

43. The amino acid composition of leaf protein on a g per 16g nitrogen (16 g N X 6.25 (conversion factor) = 100 g protein) is presented in Table 9.

Table 9. Amino Acid composition in the protein of cassava leaves and meal (g/16g nitrogen)

Reference	a	b	Range
Arginine	4.0 – 5.7	5.1	4.0 – 5.7
Histidine	1.1 = 2.5	2.7	1.1 – 2.7
Isoleucine	3.9 – 5.0	4.3	3.9 – 5.0
Leucine	7.2 – 8.9	4.7	4.7 – 8.9
Lysine	3.8 – 7.5	7.1	3.8 – 7.5
Methionine	1.3 – 2.0	1.1	1.1 – 2.0
Phenylalanine	5.3 – 5.4	3.6	3.6 – 5.4
Threonine	3.2 – 5.0	4.7	3.2 – 5.0
Tryptophan	2.0	1.0	1.0 – 2.0
Valine	5.1 – 5.7	6.4	5.1 – 6.4
Cystine	0.7 – 1.4	1.0	0.7 – 1.4
Glycine		4.6	4.6

a – Eggum (1970) leaves
b – Devendra (1977) meal

4. Lipids

44. Lipid composition of cassava roots has not been studied extensively, as it occurs in such low concentrations. Total lipids in fresh cassava roots average at 0.25% (Lalaguna and Agudo, 1988). Figures for phospholipids, glycolipids and neutral lipids are presented in Table 10. Polar lipids plus sterols and steryl esters made up the major part (77.9%) of the extracted lipids. Of the seven phospholipids identified, phosphatidylcholine occurred in the highest concentration (265.4 nmol/g fresh wt), while of the six glycolipids identified, digalactosyldiacylglycerol occurred at the highest amount (333.2 nmol/g fresh weight). Free sterols were at an average of 304.3 nmol/g fresh wt. and triacylglycerol was measured at 444.4 nmol/g fresh wt. Young cassava leaves have a low content of lipids (3.02%) of which 22.4, 25.1 and 48.2 were non-polar lipids, glycolipids and phospholipids, respectively (Khor and Tan, 2006). Non-polar lipids of the leaves contained 2.1% fatty acids, and with the exception of steryl esters, all leaf lipids have a high content of polyunsaturated fatty acids (Khor and Tan, 2006).

Table 10. Lipid composition of cassava roots (fresh weight *)

Lipid	nmol/g fresh wt
Total phospholipids	706.0
Total glycolipids	818.6
Total neutral lipids	892.6

Lalaguna and Agudo (1988)
* The concentrations are not converted to dry weight because the lipids are presented as lipid combinations.

45. The major fatty acids of cassava root meal lipid are oleic and palmitic acids. Other fatty acids found in cassava roots are linoleic, linolenic, palmitoleic, stearic, myristic, pentadecanoic, heptadecanoic and nonadecanoic acids (Ezeala, 1985).). Fatty acid compostion of raw cassava roots are summarized in Table 11. Fermentation of cassava processed roots does not alter the profile of composition of fatty acids but causes an increase in the concentration of saturated fatty acids. Stearic acid increased by about 92.6%, while linoleic acid was reduced by 72% (Ezeala, 1985).

Table 11. Fatty acid composition of raw cassava roots (dry matter)

Fatty acid	USDA
14.0	
15.0	
16.0	0.12
16.1	
17.0	
18.0	0.01
18.1	0.13
18.2	0.05
18.3	0.03

U. S. Department of Agriculture, Agricultural Research Service. 2008. National Nutrient Database for Standard Reference, Release 21
http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl

Note: The data was converted to a dry matter basis using the water level given in the table.

Table 12. Fatty acid composition of unfermented and fermented cassava tuber meals and the effect of fermentation on the fatty acid content

Fatty acid	Fatty acid (g/kg dry tuber meal)[a]		Fatty acid (% total fatty acid)[a]	
	Unfermented	Fermented	Unfermented	Fermented
14.0	0.06	0.08	1.2	1.2
15.0	0.03	0.06	0.6	0.9
16.0	1.50	2.10	31.0	31.4
16.1	0.20	0.22	4.1	3.3
17.0	0.02	0.03	0.5	0.5
18.0	0.13	0.34	2.7	5.2
18.1	1.80	2.46	37.5	37.2
18.2	0.70	1.02	14.5	15.4
18.3	0.38	0.30	7.9	4.6
19.0	tr	0.02	tr	0.3

tr = trace
a means of three different determinations
Ezeala, 1985.

5. *Minerals*

46. The mineral content of cassava roots and leaves is shown in Tables 13 and 14, respectively. The FAO lists the calcium and iron content of processed root flour as 0.74 g/kg dry matter and 4.0 mg/g dry matter, respectively.

47. Hung Nguyen *et al.* (2002) tested the effect of different levels of NPK fertilizer on the elemental composition of cassava leaves four months after planting. Increased rates of NPK in a ratio of 2 : 1 : 2 ($N:P_2O_5:K_2O$) significantly increased concentrations of N, P, K, S, Mn and Cu while reducing concentrations of Mg and Ca.

Table 13. Mineral element concentration in cassava roots (dry matter basis)

References	a FAO	b USDA	c	Range
Mineral	**g/kg**			
Calcium	1.1	0.26	0.31-2.5	0.26 - 2.5
Phosphorus	-	-	0.71-3.2	0.71-3.2
Magnesium	-	-	0.52-2.4	0.52-2.4
Potassium	-	-	-	-
Sodium	-	-	0.02-1.23	0.02-1.23
Mineral	**mg/kg**			
Iron	3.0	0.4	6.0-230.0	0.4-230.0
Manganese	-	-	0.45-5.0	0.45-5.0
Copper	-	-	0.79-40.3	0.79-40.3
Zinc	-	-	2.63-37.5	2.63-37.5
Aluminium	-	-	4.4-330	4.4-330

a - FAO (2005)
b. – USDA (2005)
c - Chavez *et al.* (2005)

Table 14. Mineral element concentration in cassava leaves and processed leaf products (dry matter basis)

References	Leaves			Leaf Meal		
	Dried	**Fresh**	**Range**	**Dried**	**Dried**	**Range**
	a	**b**		**c**	**d**	
Mineral			**g/kg**			
Calcium	3.6-6.2	2.1-9.7	2.1-9.7	17.4	9.2	9.2-17.4
Phosphorus	1.6-2.8	3.1-4.2	1.6-4.2	3.6	3.0	3.0-3.6
Magnesium	2.0-4.1	2.8-4.3	2.0-4.3			
Potassium	9.5-22.3	15-24.8	9.5-24.8			
Sodium	-	0.26-1.1	0.26-1.1			
Sulphur	3.0-3.8	-	3.0-3.8			
Mineral			**mg/kg**			
Iron	800-2000	16.1-86.4	16.1-2000			
Manganese	140-200	12.9-26.5	12.9-200			
Copper	5.5-7.4	3.6-17.7	3.6-17.7			
Zinc	61-81	8.4-28.9	8.4-81.0			

a - Hung Nguyen *et al.* (2002). Fully expanded leaves, third and fourth from the top four months after planting
b - Achidi *et al.* (2003)
c - Yousuf *et al.* (2007)
d- Vongsamphanh and Wanapat (2004)

6. Vitamins

48. Vitamin levels in cassava roots and leaves from mature plants are low, with carotene being the most important identified vitamin. Carotene levels in roots vary widely amongst cassava cultivars or varieties (Iglesias *et al.*, 1997). A study by Chavez *et al.* (2005) of 1,789 accessions for the CIAT germplasm bank showed a range of 0.102 to 1.04 mg/kg fresh weight, with an average of 0.2457 mg/100 g fresh weight (0.717 mg/100 g dry weight), while figures from the FAO showed low levels in bitter cassava of 0.24 mg/kg DM. Other key vitamins are ascorbic acid (vitamin C), thiamine, riboflavin and niacin. Again these vary according to the cultivar and age of the cassava plants (Table 15). Cassava leaves, however, are rich in proteins and vitamins, especially the young leaves that are usually eaten by humans (FAO, 2007). Nhu Phuc *et al.* (2000) analyzed six cassava varieties from South Vietnam, India and Japan. They found that cassava leaves are high in ascorbic acid, thiamine and β-carotene.

Table 15. Vitamin content of cassava roots and flour (kg dry weight)

	Roots FAO^a	Roots USDA ^{b}	Roots Range	Flour FAO^c
Provitamin A (β-carotene (μg))	24	1.3	1.3 – 24.0	0
Vitamin B$_1$ (mg)	48	-	48	-
Vitamin B$_2$ (mg)	0.06	-	0.06	0.07
Vitamin B$_6$ (mg)	0.08	-	0.08	0.06
Niacine (mg)	0.9	1.4	0.9 – 1.4	0
Folic acid (μg)	38	-	38	-
Vitamin C (mg)	50	32	32 - 50	4.5

a - FAO, 2007
b - U. S. Department of Agriculture, Agricultural Research Service. 2008. National Nutrient Database for Standard Reference, Release 21; http://www.nal.usda.gov/fnic/foodcomp/cgi-bin/list_nut_edit.pl
c - FAO, 2007a.

B. Processed cassava products

49. Table 16 illustrate some of the nutrient composition of cassava flour, used in a variety of flour based products. Cassava tapioca and starch have an average of 0.50 g protein and 0.33 g fat/100 g dry matter.

Table 16. Nutrient composition of processed cassava roots (g/100 g dry matter)

Peel Meals				**Cassava meal or root meal or flour**					
Reference	**a**	**b**		**c**	**d**	**e**	**f**	**g**	**Range**
		Fermented	**Unfermented**						**Total**
Crude protein	5.9	5.3	5.1	1.8	2.9	3.2	2.6	1.6	1.6-3.2
Crude fibre	13.4	11.5	11.3	0.5	3.2	6.3			0.5-6.3
Fat^h	1.2	0.7	0.8	0.6	1.9	0.8		0.3	0.3-1.9
Ash	10.8	9.3	4.9	0.3	1.7	1.8	0.8		0.3-1.8
NFE^i	68.9	63.9	67.4	92		83.8*		87.7**	83.8-92.0
NDF^j					9.3		3.1	9.8	3.1-9.8
ADF^k					3.6		1.8	3.0	1.8-3.6

a - Salami (2000)
b – Osei *et al.* (1990)
c – FAO 2007
d - An *et al.* (2004)
e - Aregheore *et al.* (1988) * Starch. Peeled tubers
f - Sable *et al.* (1992)
g - Kozloski *et al.* (2006) ** Non-fibre carbohydrates
h– Ether extractable fat
i – Nitrogen free extract
j – Neutral detergent fibre
k – Acid detergent fibre

50. The composition of processed cassava leaves and cassava hay is presented in Table 17. Processed leaves are used in the feeding of monogastric animals such as pigs and poultry (Nhu Phuc *et al.*, 2000; Du Thanh Hang and Preston, 2005) as well as for ruminants, while the foliage, consisting of leaves and stems, is fed almost exclusively to ruminants (Wanapat *et al.*, 1997; Tien Dung *et al.*, 2005). The composition of the foliage including the hay would depend on the proportion of leaves and stems, the latter with, for instance, lower protein content (Tien Dung *et al.*, 2005).

Table 17. Nutrient composition of processed cassava leaves and foliage (g/100 g dry matter)

	Leaves			**Foliage***					
References.	**a**	**a**	**b**	**c**	**d**	**e**		**f**	**Range**
	Silage	**Meal**	**Meal**	**Hay**	**Hay**	**Fresh**	**Hay**	**Hay**	
Crude protein	27.6	26.0	26.8	20.6	24.9	23.2	27.3	18.9	18.9-27.3

Crude fibre	17.1	16.1							
Fat	13.9	9.9	5.8					9.8	9.8
Ash	10.3	10.9		7.5	6.6	6.1	8.0	10.7	6.1-10.7
NFE[g]	31.1	37.1						39.5	39.5
NDF[h]	33.5	33.5	26.1	55.0	34.4	55.6	67.7	29.7	29.7-67.7
ADF[i]			13.4	38.9	27.0	30.0	41.7		27.0-41.7
ADL[j]				16.8	3.8	11.0	13.2		3.8-13.2

* Leaves, stems and petiole

a - Nhu Phuc *et al.* (2000)
b - Yousuf *et al.* (2007)
c - Kiyothong & Wanapat (2003) Whole plant at 3 months after planting
d - Wanapat *et al.,* (1997)
e - Vongsamphanh & Wanapat (2004): Harvested at 3, 5 and 7 months
f - Tien Dung *et al.* (2005)
g - Nitrogen free extract
h - Neutral detergent fibre
i - Acid detergent fibre
j – Acid detergent lignin

51. Table 18 shows the contents of protein and energy of cassava products and by products used in animal feed.

Table 18. Protein and energy content of cassava products and by-products used in animal feed

Products and by-products	Moisture %	Metabolizable Energy /kg	Crude Protein %
Fresh roots	65	1.3	1.2
Root silage	60	1.4	1.4
Dried roots	13	3.1	2.8
Fresh foliage	72	0.3	6.1
Foliage silage	68	0.4	6.4
Foliage dry	13	1.1	22.0
Fresh bran	90	0.5	0.9
Dry bran o	13	2.3	2.9
Mancha fresca	90	0.5	0.8
Mancha seca	13	2.7	2.8

Ceballos and Ospina, (2002)

SECTION III – OTHER CONSTITUENTS

A. Anti-nutrients

1. *Tannins*

52. Tannin concentrations are low in the varieties studied (Achidi, 2003). Low levels of tannins (proanthocyanidins) have been found in dried cassava using a direct vanillin assay (compared to other direct methods of analysis based on acid hydrolysis and protein precipitation) (Rickard, 2006). Tannins have been found in leaves, the highest (29.7g/kg dry weight) being in fresh red cassava leaves (Awoyinka *et al.,* 1995). Tannin levels decline rapidly to a range of 2 to3 g/kg dry matter after drying (Table 19). Cassava leaves also contain tannin-protein complexes (Wanapat, 1995). Reed *et al.* (1982) showed that the processing of the cassava leaf affects the tannin content.

53. Vongsamphanh & Wanapat (2004) found that cassava foliage harvested at 3, 5, and 7 months after planting did not change much in condensed tannin content, with an average value of 3.48 (±0.19) g/100 g dry matter. According to Kiyothong & Wanapat (2003) and Tien Dung *et al.,* (2005) cassava hay contained 3.3 and 2.3 (± 0.65) g condensed tannin/100 g dry hay, respectively. Vongsamphanh & Wanapat (2004) and Tien Dung *et al.* (2005) used the vanillin-HCl method for condensed tannin.

Table 19. Tannin content (Vanillin - HCI assay) of cassava leaf meal as influenced by processing methods (g/kg dry matter)

	Oven – drying		**Sun - drying**	
Wilting (days)	**Full**	**Chopped**	**Full**	**Chopped**
0	2.8	2.6	2.9	2.7
1	2.5	2.5	2.4	2.4
2	2.5	2.4	2.4	2.4
3	2.4	2.4	2.2	2.3

Source : Ravindran *et al*. (1987)

2. *Phytic Acid*

54. The anti-nutritional effect of phytin arises from its ability to chelate divalent cations such as Ca, Mg, Fe and Zn (Forbes and Erdman, 1983). This renders the metals metabolically unavailable. Non-ruminants (including humans) lack phytase to break down phytin so that phosphorus can be released for metabolism. A high proportion of the phosphorus present as the poorly digestible phytin-P could lead to considerable amount of dietary phosphorus being voided in faeces, Reed *et al.* (1982) showed that the processing of the cassava leaves affects the phytin acid content, as shown in Table 20.

Table 20. Phytic acid content (mg/100 g) in differently processed cassava leaves (Mean, n=2)

Processing Variables	**Cassava Varieties**

	(MS 6)	**(TMS 30555)**	**(TMS 30572)**	**(Local)**	**Phytin retained (%)**
SND	45.7 (18)	37.6 (18)	86.5 (41)	93.1 (87)	41.1±32.0
OVD	184.9 (74)	126.4 (64)	13.0 (64)	81.1 (76)	69.4±6.4
STM	213.9 (86)	238.1 (120)	258.8 (120)	198.5(184)	127.7±41.2
SHD	75.6 (30)	101 (51)	75.1 (35)	71.2 (66)	45.8±16.4
STP	269.8(108)	228.1 (115)	288.9 (135)	136.0(126)	121.3±12.0
STM + SND	98.9 (40)	49.2 (25)	62.6 (29)	78.3 (73)	41.7±21.7
SHD + SND	106.7 (43)	94.8 (48)	69.8 (33)	44.4 (41)	41.1±6.4
Fresh unprocessed leaves	249.1(100)	197.8 (100)	213.8(100)	107 (100)	(100)

SND, Sundrying; OVD, Oven-drying; STM, steaming; SHD, shredding; STP, steeping;
Values in parenthesis refer to % Phytic Acid retained

Reed *et a*l., (1982)

3. *Oxalate, Nitrate, Polyphenol, Saponin, Trypsin inhibitor*

55. Wobeto *et al.,* (2007) studied the antinutrient levels in five different cultivars of cassava leaf meal at three different stages of growth appropriate for human consumption. The lowest oxalate levels were found in the 12-month old cultivars, except for cultivars Ouro do Vale and Maracanã, while the nitrate levels decreased with the maturity of the plant. Table 21 shows the polyphenol content, trypsin inhibitor and saponin activity from these five cultivars. In general, it is observed that the polyphenol contents increased with the maturity of the plant. The polyphenol contents found in cassava leaf meal are according to those reported in the available literature, that is, 2.1 to 120mg/100 g dry matter.

Table 21. Average contents of polyphenol, trypsin inhibitor, saponin in activity in cassava leaf meal at three ages of the plant

Cultivars	**Polyphenol (mg/g dry matter**			**Trypsin inhibitor (ITU$^{2\ *}$.mg/ g dry matter**		
	12 mo*	**15 mo**	**17 mo**	**12 mo**	**15 mo**	17 mo
Ouro do Vale	61.49	52.29	92.31	2.75	1.88	2.80
Maracanã	43.37	75.31	106.43	1.09	2.54	2.46
MANT.IAC	48.58	60.51	95.78	1.48	1.98	2.61
IAC 289-70	47.33	59.69	71.15	0.86	2.43B	2.95
Mocotó	44.13	78.86	79.88	0.57	3.13	3.28
Cultivars	**Saponin (g.100 / g dry matter**					
Ouro do Vale	1.74	2.48	3.62			
Maracanã	2.28	3.20	4.43			
MANT.IAC	2.95	3.35	3.61			
IAC 289-70	3.13	4.33	4.07			
Mocotó	4.41	4.73	4.38			

Wobeto, *et al.,* 2007.

MO*- months

B. Toxicants - cyanogens

56. The cyanogenic potential varies greatly in the varieties studied (Achidi, 2003). The cassava plant carries two cyanogenic glucosides, linamarin and lotaustralin, in the edible portion of its roots and leaves. The amounts of these potentially toxic compounds vary considerably, according to cultivar and growing conditions.

57. Some varieties have sufficiently high levels to require domestic processing in order to remove the toxins. Linamarin, when hydrolyzed, yields hydrocyanic acid (HCN) which is toxic to animals. In small doses, cyanide is detoxified to thiocyanate by means of the enzyme rhodanase, which use methionine as the first limiting amino acid in cassava feed. Most of the cyanide can be eliminated by crushing or fermentation followed by heating. The detoxification product thiocyanate is a potent goitrogen. Moreover, the sugars in cassava may react with the e-amino group of lysine in a Maillard reaction, making lysine unavailable and the second limiting amino acid. The cyanogen's levels can vary in cassava varieties [in leaves (*200–1300 mg CN equivalents/kg dry weight*) and roots (*10–500 mg CN equivalents/kg dry weight*)], and for many of them they exceed the maximum recommended cyanide level in foods (10 mg CN equivalents/kg dry weight) established by the FAO.

58. The cyanogen content of cassava foods can be reduced to safe levels by maceration, soaking, rinsing and baking; however, short-cut processing techniques can yield toxic food products. The hydrocyanic acid potential (HCN_p) of fresh cassava leaves is influenced by the stage of maturity (Table 22), and also by processing methods such as oven or sun drying. For example, this can vary from 1436 mg HCN_p /kg dry matter in freshly harvested cassava leaves before chopping, to an average of 1045 mg HCN_p /kg dry matter three hours after chopping. Drying also results in a reduction in HCN_p from 88 - to -96% of the initial level in freshly harvested leaves.

Table 22. Hydrocyanic acid potential (HCNp) of fresh cassava leaves as influenced by stage of maturity

Stage of maturity	Leaf no. from apex	HCN_p (mg/kg dry weight)		
		Petioles	Leaf blades	Whole leaves
Expanding	1 – 4	5198	3161	4073
Just fully-expanded	5 – 7	1731	1962	1766
Mature	8 – 11	609	774	745

Source: Ravindran *et al.* (1987).

P - potential

59. In cassava leaf meal, the HCN_p is also influenced by storage time during which levels can decline by 14.2 to 58.2% of initial levels (Table 23). Many cassava products contain very low amounts of cyanogens, which can be efficiently eliminated by the body if the protein intake is adequate. Fasuyi (2005) subjected cassava leaves to different processing to deliberately reduce the high level of cyanogenic glycosides present in the leaves. A combination of shredding and sun-drying seemed to be most effective to reduce the cyanide content.

Table 23. Hydrocyanic acid potential (HCNp) and crude protein contents of cassava leaf meal as influenced by storage time (dry matter basis)

Storage time (months)	HCN_p (mg/kg)	HCN loss as a percentage of initial level	Crude protein (g/kg)
0	91	-	227
1	78	14.2	-
2	68	25.3	226
3	59	35.2	-
4	49	46.2	217
5	43	52.7	-
6	40	56.0	209
7	38	58.2	-
8	38	58.2	203

Ravindran *et al*. (1987)

C. Allergens

60. Cassava is not a commonly allergenic food.

61. However, in recent years there have been six reports that described seven individuals who had suffered adverse allergy-like symptoms after oral ingestion or topical exposure to cassava (Caraballo, 2001; Chiron, 2001 Gasper, 2003; Galvao, 2004; Gaspar, 2004; Ibero, 2004). One highly atopic allergy sufferer who was also allergic to milk, soy, wheat, corn, egg, nuts, peanut, multiple fruits and vegetables reacted to tapioca in a double-blind placebo controlled challenge (Chiron, 2001). The remainder of the subjects tested positive for latex-fruit allergy. Cassava can thus be added to the list of fruits and vegetable to which latex allergy positive subjects could potentially cross-react.

62. Latex is a relatively recently characterized allergenic substance that shares cross-reactivity with proteins in many unrelated food plants. The latex-cassava sensitive subjects displayed positive skin prick tests with cassava extracts and their sera cross-reacted with latex allergens. Additionally, latex allergens inhibited IgE binding to cassava allergens. The latex allergens have been identified and characterised at the molecular level (Kurup *et al*., 2005), however, the number and sequences of the epitopes present in each of these allergens has not been reported.

SECTION IV- SUGGESTED CONSITUENTS TO BE ANALYZED RELATED TO FOOD USE

A. Food uses and products

63. Cassava is grown for its enlarged starch-filled roots which contain nearly the maximum theoretical concentration of starch on a dry weight basis among crops. Cassava can be grouped as either the "sweet" (edible) variety or the "bitter" (poisonous) variety. Nutritionally, the cassava is comparable to potatoes, except that it has twice the fibre content and a higher level of potassium.

64. Around the world, cassava is used in a variety of food products: as vegetables in dishes, grated to make pancakes, dried and ground into tapioca flour, or sliced and made into snack chips etc. Roots are prepared much like potato. They should be cooked before eating, for reducing potentially toxic concentrations of cyanogenic glycosides to innocuous level. Thus they are usually peeled and boiled, baked, or fried. After peeling, the roots are sometimes grated and the sap extracted through squeezing or pressing. The cassava mixture is then further dried over a fire to make a meal or it is fermented and cooked. The dried meal can then be re-hydrated with water or added to soups or stews. Roots for human consumption, are eaten after cooking or in processed forms (see Figure 1). Bitter varieties are peeled, and the root grated to make a pulp that is left to ferment slightly before being pressed, dried and roasted. Some of the processed food products are known as *farinha*, *gari, foufou or gablek*. For example, gari accounts for 70% of Nigeria's total cassava consumption. In addition, alcoholic beverages can be made from the roots.

65. The leaves of cassava plant can be used and cooked similar to spinach. The young leaves are harvested for human consumption as a green vegetable or as a constituent in a sauce eaten with main staple meals (Lancaster and Brooks, 1983). Cassava leaves are consumed to varying degrees in the growing regions of Africa, constituting a major component of the diet in some countries. Their role in the diet is very different from that of the roots. Despite its substantial importance, the level of cassava leaf production or consumption is not reported in current agricultural statistics. The first matured leaves up to leaf position nine or ten are selected for consumption. The tender petioles and stem are also taken. There are country variations in the preference for particular varieties based on petiole colour and mild mosaic infection. Prior to cooking, cassava leaves are usually pounded or ground with pounding being the more popular method.

B. Suggested analysis for food use

66. The key nutrients suggested to be analysed in roots and leaves with appropriate methodology, in new varieties of cassava intended for human consumption are shown in Table 24.

67. Since all cassava food products used by consumers and industry are derived from fresh or processed material, it would be considered sufficient, in most circumstances, to analyse key constituents only in fresh roots and leaves. It would not be necessary to perform separate analysis in commodities such as dried cassava roots, cassava flour, starch or cassava pellets. Some constituents, such as fatty acids, do alter in fermented cassava products such as *gari*, but since there are (i) a variety of ways in which cassava carbohydrates are fermented, (ii) a wide diversity of micro-organisms used in these processes in a range of geographical areas, and (iii) a number of products produced during fermentation (Brauman *et al.*, 1996; see CIAT Website), it would not be practical to attempt to measure key constituents in these fresh cassava-derived products. It should also be noted that most cyanogens are usually removed during cassava processing.

Table 24. Suggested constituents to be analysed in fresh roots and leaves of cultivated *Manihot esculenta* Crantz

Constituent	Fresh leaves	Fresh roots
Proximate	X	X
Starch		X
Cyanogenic glycosides	X	X

68. Cassava is not grown for its minerals and vitamins, which occur in low amounts. Therefore, it would not be necessary to analyse for these constituents, unless the breeding objective was to produce higher levels of carotene and trace elements (one of the aims of the Bio-fortification Program) (Sautter *et al.,* 2007) in which case these should be included in root analysis.

SECTION V - SUGGESTED CONSTITUENTS TO BE ANALYZED RELATED TO FEED USE

A. Livestock feed uses

69. Cassava has long been recognised as appropriate for animal feed, largely used at low cost in many European countries. Roots, leaves and by-products are usable as feed for livestock. Cassava is used in most tropical areas for feeding of pigs, cattle, sheep and poultry. It is estimated that approximately 4 million tonnes of cassava peels are annually produced as a by-product in Nigeria alone during processing of cassava roots (Hahn, 1989). In some countries, cassava is now used as a partial substitute for maize. By-products from cassava processing are widely used to feed chicken and goats in the traditional sector. In Brazil and many parts of Asia, cassava roots, stems and leaves are chopped and mixed into a silage for feeding of cattle and pigs. In Asia, cassava production is focused on animal feed in the form of chips and pellets for export, while in Latin America 30% of cassava produced is used for domestic animal feed, compared to less than 2% in Africa (see FAO News Website).

70. Cassava roots contain a very small amount of protein (0.7 to 2%) which is of poor quality; therefore, a supplementary source of protein is needed for animal feed (Oke, 1978). Leaf protein concentrate appears more effective, but fishmeal is still the protein source of choice. Supplementation with lysine and methionine is also suggested for maximum efficiency. Oils are also important, and supplementing with palm oil is suggested as it is easily digestible, improves palatability and is readily metabolized. A combination of oil and molasses (or sugar) seems even more effective. Cassava may also affect the mineral balance resulting, for example, in parakeratosis in chicks, but this can be eliminated by the addition of zinc carbonate (Oke, 1978).

71. Powdered starch can produce ulcerogenic effects upon the gastric mucosa of some animals and so cassava-based feeds are best served as pellets. The high fibre and ash content of cassava are not only deleterious but also limit the choice of other ingredients, which are high in these components. However, with proper management cassava can be used as a substitute for maize in animal feed.

72. Cassava leaf preparations have a relative high protein ranging from 18.9 to 27.3 g/100g dry weight. Cassava leaf yields can be as much as 4.6 tonnes dry matter per hectare, at the time of the reporting of the nutrition papers (1970), most of the cassava forage material is returned to the soil as a ‘green manure product. However, there is an increased interest in using leaf products for animal feed (Ravindran, 2008). Ruminant animals can be fed fresh cassava forage, including tender stems, with good results. However, monogastric animals should not be fed cassava leaf products unless they have been processed by heating or curing to lower the cyanogenic glycoside content to a negligible level. Cassava leaf meal is high in lysine, but deficient in methionine. Some report it to have marginal tryptophan content. Still others (Oguntimein, 1988) reported cassava leaves to be deficient in isoleucine and threonine in addition to methionine. Its high tannin content appears to cause a lower amino acid digestibility probably because tannins form an indigestible complex with proteins (Ravindran, 2008).

73. In ruminant nutrition the extent of protein degradation in the rumen is an important criterion of protein quality of a feed. Using the *in sacco* technique, Wanapat *et al.*(1997) found the effective protein degradation of the protein in cassava leaves to be 47%, that in branches, 28%, in the stems, 56.9%, and the whole crop, 48.8%. In the same laboratory Promkot & Wanapat (2003) obtained effective crude protein degradability for cassava hay of 54.6%. This is a relatively low degradation compared to other plant

protein sources, and is suggested that this is due to the relatively high condensed tannin content in cassava foliage.

74. Ravindran (2008) reported that there is a good potential for the use of low levels of cassava leaf meal for poultry and swine diets. Considering that the diet of animals should contain Ca and P in a ratio of 2-1.5: 1, it is clear that cassava roots and root meal are grossly deficient in Ca. Leaves on the other hand have a better Ca: P ratio, though from an animal nutritional point of view it could even be deficient in P. In the case of monogastric animals a proportion of the P would probably be in a phytate form which is not available to the animal, typical of that of most P in plants.

B. Suggested analysis for feed use

75. The key nutrients suggested to be analysed in roots and leaves with appropriate methodology in new varieties of cassava, intended for animal consumption is shown in Table 25.

76. Since all feed products of cassava consumed by animals are derived from fresh or processed leaves and roots, it would be considered sufficient, in most circumstances, to analyse key constituents only in fresh roots and leaves. It would not be necessary to perform separate analysis of key constituents in commodities such as dried cassava roots, cassava flour, starch or cassava pellets. The constituents of key importance are the proximates (crude protein, crude fat, crude fibre, ash), acid detergent fibre, neutral detergent fibre, starch, calcium, phosphorus, cyanogenic glucosides (linamarin and lotaustralin), phytic acid, and tannins. Some constituents, such as fatty acids, are either in low concentration in the root products, or in the case of the leaf products are fed in such a low amount as to make only a neglible contribution to the total fatty acid requirement of animals. Cassava is not grown for its minerals and vitamins, which occur in low amounts, and therefore it would not be necessary to analyse for these constituents with the exception of calcium and phosphorus, unless the breeding objective is to produce higher levels of carotene and trace element (one of the aims of the Biofortification Program) (Sautter *et al.*).

Table 25. Suggested constituents to be analysed in cassava matrices for animal feed

Constituent	Fresh leaves	Fresh roots
Proximate	X	X
Acid detergent fibre	X	X
Neutral detergent fibre	X	X
Starch		X
Calcium	X	
Phosphorus	X	
Cyanogenic glycosides	X	X

SECTION VI – REFERENCES

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Etc… [to be completed in ENV/JM/FOOD(2006)6/REV3/ADD1]

APPENDIX – BIOLOGY OF CASSAVA

A. Definitions of terms relating to cassava

77. Some of the terms commonly found in literature to describe parts, types and uses of cassava and used in this document are defined below:

Term	**Definition in this document**
Cassava roots:	The enlarged starch filled root portion of cassava plant, sometimes wrongly called starchy tuber
Cassava peels:	Outer cover of the starchy root that is usually removed manually with sharp knife with little or no pulp
Cassava leaves:	The vegetative part of the plant used as vegetable and leaf meal
Sweet cassava:	Edible cassava variety (low anti-nutrient variety)
Bitter cassava:	Poisonous cassava variety (high anti-nutrient variety)
Cassava flour/meal:	Dried milled cassava roots used mainly for human consumption. Includes flour, meal and flakes
Cassava chips:	Dried un-milled cassava
Cassava starch:	Industrial outlet for cassava used in paper, textile and food industries
Dried cassava:	Includes peeled, sliced and sun-dried (chips) and ground and compressed cassava (pellets) used mainly as livestock feed
Tapioca:	Obtained from cassava starch & used in the preparation of puddings and infant feed

Source: www.unece.org/stats/econ/

B. Natural history

78. Cassava is native to tropical America (Olsen & Schaal, 2001), and is known as *Manihot esculenta* Crantz. It is also known amongst rural populations in various countries as yuca, manioc and mandioca (see UNECE Website). Cassava (*Manihot esculenta* Crantz) was originated in Brazil (Schaal *et al.* 1994) and has been cultivated for more than five hundred years, first by the Indians in Latin America. It was later introduced to Africa and Asia where it forms the subsistence base of the poorer populations in the marginal areas of these continents. It presents wide genetic diversity that is concentrated mainly in Latin America and the Caribbean. Approximately 8 500 cassava accessions are kept in the various collections at world level, of which 7 500 are found in South America (Costa & Morales, 1994). In Brazil 4 132 accessions have been collected that are maintained in germplasm banks throughout the country (Fukuda, 1991; 2000).

79. Allem (1994) proposed that the modern cultivated cassava varieties and landraces, *M. esculenta* subsp. *esculenta*, originated directly from the extant wild subspecies *M. esculenta* subsp. *flabellifolia* Pohl in the forests of Central Brazil. *M. esculenta* subsp. *flabellifolia* is thought to have been domesticated as early as 6000 B.C. (Gibbons, 1990). This close relationship has since been supported by studies of Roa e*t al*. (1997; 2000) using amplified fragment length polymorphism (AFLPs) and Microsatellites to estimate genetic relationships. A detailed phylogenetic molecular analysis based on the sequence of a single-copy nuclear gene encoding glyceraldehyde 3-phosphatedehydrogenase (G3pdh) (Olsen and Schaal, 1999) indicated that cassava was domesticated specifically from populations of *M. esculenta* subsp. *flabellifolia* occurring along the southern rim of the Amazon basin, in the Brazilian states of Acre, Rondônia and Mato Grosso, and likely extending south into similar vegetation in Bolivia. The premise of a southern Amazonian domestication has been further supported by subsequent studies (Olsen and Schaal, 2001; Léotard and McKey, 2004).

80. The 98 known wild species of the New World genus *Manihot* are distributed across warm regions of the New World, from southern Arizona to Argentina (Rogers and Appan, 1973). There are two centres of species diversity in the genus; most species occur in northern South America (~80 species), and a secondary centre of diversity occurs in Mexico and Central America (17 species, plus the related taxon *Manihotoides pauciflora*). Central Brazil has the highest diversity of *Manihot* species, and is home to about 40 wild species. Most *Manihot* species occur in dry or seasonally dry conditions. Although a few species are found in rain forests, they tend to be sporadic in their distributions, and never become dominant members of the local vegetation (Rogers and Appan, 1973). The habit of *Manihot* species ranges from low herbaceous vines to trees exceeding 12 meters (Rogers and Appan, 1973).

81. Cassava was introduced in the 16th century to West Africa through Portuguese sailors, and on the East coast of Africa via Zanzibar and Madagascar at the end of the eighteenth century and was later introduced into Asia by traders (Ceballos et. al. 2004).

C. Biology

82. Cassava (*Manihot esculenta* Crantz), a perennial woody shrub, produces storage roots within six months to three years. The average height of the plant is about one meter. The leaves have a palmate formation and form a massive, shady canopy that is conducive to soil fertilization and suppression of weed growth. The cultivars are traditionally characterized as high or low cyanide content. They can also be grouped into high and low starch varieties for commercial application, edible lines for human consumption and lines suitable for animal feed. It has the ability to grow on marginal lands where cereals and other crops do not grow well. It can tolerate drought and can grow in low-nutrient soil. The roots can be stored in the ground for up to 24 months and some varieties for up to 36 months. (Babaleye, 1996). The cassava plant bears separate male and female flowers on the same plant, making it monoecious. The time interval from planting to flowering depends on the specific genotype and environmental conditions, and may vary from 1 to more than 24 months. Male and female flowers are borne in a single branched panicle, with female flowers at the base, and male flowers toward the tip. Flowering may be strongly influenced by environmental factors. For breeding purposes, clones are classified into different growing zones (environments, ecotypes), so that breeders may take account of the flowering habits of the plants they wish to cross. For some clones, induction of flowering appears to depend on long photoperiods – up to 16-hour day length – associated with temperatures of around 24ºC (Keating, 1982).

83. The pollen grains of cassava are quite large in size and sticky, and wind pollination appears to be of little consequence for gene flow. Several species of wasps (mainly *Polistes spp*.) and honeybees (*Apis mellifera*) are the main pollinators in Colombia and Africa, respectively (Kawano, 1980). Cassava pollen shows size dimorphism, the larger grains being 130 to 150 microns in diameter, whereas the smaller grains range from 90 to 110 microns (Plazas, 1991). Both self and cross-pollination may occur naturally in

cassava. While there appear to be no genetic barriers to fertilisation between clones of cultivated cassava, the need for synchronous flowering represents a major hurdle in cassava breeding (Ceballos *et al*., 2004), and is presumably no less a barrier to natural gene flow between diverse stands of cultivated cassava.

84. Seed production and viability are variable, depending largely on the quality of the female parent (Kawano, 1980). Jennings (1963) reports that one viable seed per fruit is normally achieved in controlled pollinations, from a maximum of three possible in the trilocular ovary. Ceballos *et al.* (2004) indicate that one to two viable seeds are obtained from each hand-pollination. Newly harvested seeds are dormant, requiring 3 to 6 months of storage before they will germinate (Jennings and Iglesias, 2002). Seed production and viability are variable, depending largely on the quality of the female parent (Kawano, 1980). Botanical seed is not typically used for commercial propagation. Genetically, any particular cassava genotype is extremely heterogeneous, and propagation from sexual seed results in wide and unpredictable diversity of phenotypes, which is of interest to breeders but presents difficulties in propagation (Ceballos *et al.,* 2004). Propagation of cassava is, therefore, typically accomplished by vegetative cuttings in order to preserve the known characteristics of favoured lines, as described below. Heterozygous volunteers resulting from natural outcrosses are preferentially retained, since they are larger and much more vigorous than inbred seedlings, which can suffer from inbreeding depression (Kawano, 1980). This practice contributes to the maintenance of genetic diversity in cultivated populations (Pujol *et al*., 2005). Seedlings are initially smaller than plants developed from stakes and require special care to become established and prosper.

85. Cassava is normally propagated by means of stem cuttings, which are known horticulturally as ‘stakes’. Stakes are typically at least 20 cm long, and have 4 to 5 nodes with viable buds. Stakes must be transported carefully to avoid damage, and may be treated with agrochemicals to prevent pest or disease establishment in the new plants. Stakes must be matured to the point that they do not dry out too quickly when planted, but must not be over-mature.

D. Breeding and Gene Flow

86. Rogers and Appan (1973) states that in the genus *Manihot* about 98 species are recognized and that they all originate from four regions of diversity in Brazil and Central America. All of those that were cytogenetically studied are diploid with 36 chromosomes. Cassava has on many occasions successfully been experimentally crossed with wild *Manihot* species (Lanjouw 1939; Nichols 1947; Bolhuis 1953; Cruz 1968; Jennings 1959; Abraham 1975; Nassar 1980, 1989, 1991; Nassar *et al* 1986). Substantial work has been undertaken attempting to artificially introgress genes from wild species into cultivated cassava for breeding purposes (Nassar, 1989; Nassar *et al*., 1986; Hahn *et al*., 1990); however, such efforts have met with mixed success. The more closely related the wild species is to cultivated cassava, the more successful hybridisation. Sixteen successful crosses at CIAT between cassava and the conspecific wild progenitor *M. esculenta* subsp. *flabellifolia* resulted in ‘thousands of seeds’, whereas only five seeds of unknown viability were obtained from two crosses with *M. aesculifolia*, according to Roa *et al.* (1997). The hybridisation of feral cassava with its closely related wild relative *Manihot esculenta* subspecies *flabellifolia* has been reported and confirmed using modern molecular methods (Duputie *et al.* 2007). From the results of both artificial and natural hybridisations, it seems likely that genetic or physiological factors play a significant role in restricting gene flow from cassava to related populations. The probability of gene flow, as well as the severity of measures required to prevent it, may thus diminish rapidly with increasing evolutionary distance between the species. Most *Manihot* species do not hybridise readily with cassava (Olsen and Schaal, 2001), and we cannot assume that such hybridisation is common in nature.

87. In Africa, naturalized *Manihot glaziovii* (Ceara rubber tree) is the only reported relative of cassava. *M. glaziovii* is believed to be closely related to *M. esculenta* (Rogers and Appan, 1973). Natural hybrids with *M. glaziovii* from African collections have been identified and confirmed by morphological

and electrophoretic markers) and DNA-based RFLP marker technique (Beeching *et al.*, 1993). Certain African cultivars can also be identified as descendents of *M. glaziovii* hybrids by the same technique (*ibid.*). Naturally occurring hybrid stands have been reported (Lefevre, 1988). These reports reflect hybridisation presumably occurring with the two species in close proximity over long periods; the probability of gene flow from a particular stand of cassava to *M. glaziovii* over specific distances and a finite time period, as would be the case with an experimental confined field trial, remains to be established. *M. glaziovii* is reported to be widely distributed in other parts of the tropics as well. Rogers and Appan (1973) have reported collections of it in Asia from Laos, Sri Lanka, Malaysia, Indonesia, Philippines and India, as well as from the New World tropics and islands in the Pacific Ocean.

88. Recent breeding programs can be found in many countries, for example at Embrapa in Brazil, where high yielding, drought and bacterial blight resistant cultivars possessing apomixes and a high protein content were bred (Nassar 1979, 1980, 1991, 1994, 1997, 2000). CIAT initiated a cassava breeding program in the early 1970s with the objectives of improving yield potential and tolerance to diseases and insect pests, and adverse soil and environmental conditions. This program activity was expanded to Asia in the early 1980s in the form of an applied breeding program in close collaboration with national programs. In the decade 1990s, IITA scientists successfully bred cassava cultivars with a durable resistance to diseases of Bacteria Blight and Cassava Mosaic (CMD) (Hahn *et al.,* 1980), and more recently the potential for breeding to increase the levels of bio-available Fe, Zn, and provitamin A carotenoids significantly in the edible portions of cassava (Bouis, 1996; Graham *et al.* 2001) has been initiated.

89. When the producer considers the farming of cassava from the angle of animal feed, there are two alternatives: to direct the production at a high yield of roots or direct it towards a high yield of foliage (leaves and stems). The production of roots is preferred. Investigation into varieties and growing techniques to ensure a high production of starch and carbohydrates in the roots, which are a source of energy to feed monogastric animals is conducted. The production of the air has, in this case, a secondary importance and cannot limit the quality and performance of the roots. When the cultivation specializes in the production of foliage, high in fibre and protein that can be gained from this is important in a feeding program for ruminants. The variety of cassava and cropping systems are different depending on the production plan is chosen. It is possible to obtain excellent quality of foliage to feed ruminants if planted varieties selected for that purpose, with higher density, with proper fertilization, with cuts made in ages well defined, and with sound-processing systems. The yield and nutritional characteristics of the foliage of this type allow you to compete with legumes and with the foliage like species. The information on varieties and production systems for the production of foliage is regularly provided by the technicians of the Latin American and Caribbean Consortium of Investigative Support and Development of Yucca-CLAYUCA; have been mentioned, for example, densities from 40,000 to 112,000 plants / ha. There is agreement, however, that the first court should not happen before 3 months. The yield of dry matter foliage depends on the variety, fertilization and cultivation system. In most of the reports cite yields of 15 to 30 t/ha per year, with intervals of 3 months between cuts (Gil, 2004).