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Series on the Safety of Novel Foods and Feeds No. 18

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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No. 2, Consensus Document on Compositional Considerations for New Varieties of Soybean: Key Food and Feed Nutrients and Anti-nutrients (2001)

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Series on the Safety of Novel Foods and Feeds

No. 18

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

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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FOREWORD

The OECD's Task Force for the Safety of Novel Foods and Feeds decided at its first session, in 1999, to focus its work on the development of science-based ***consensus documents,*** which are mutually acceptable among member countries. These consensus documents contain information for use during the regulatory assessment of a particular food/feed product. In the area of food and feed safety, consensus documents are being published on the nutrients, anti-nutrients or toxicants, information of its use as a food/feed and other relevant information.

This consensus document addresses compositional considerations for new varieties of cassava by identifying the key food and feed nutrients, toxicants and allergens. A general description of these components is provided. As well, there is background material on the production, processing and uses of cassava and considerations to be taken when assessing new cassava varieties. Constituents to be analysed, related to food use and to feed use, are suggested.

South Africa served as the lead country in the preparation for this document but the draft has been revised on a number of occasions based on the input from other member countries.

The Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology has recommended that this document be made available to the public. It is published on the authority of the Secretary-General of the OECD.

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PREAMBLE

Food and feed products of modern biotechnology are being commercialised and marketed in OECD member countries. The need has been identified for detailed technical work aimed at establishing appropriate approaches to the safety assessment of these products.

At a Workshop held in Aussois, France (OECD, 1997), it was recognised that a consistent approach to the establishment of substantial equivalence might be improved through consensus on the appropriate components (*e.g.*, key nutrients, key toxicants and anti-nutritional compounds) on a crop-by-crop basis, which should be considered in the comparison. It is recognised that the components may differ from crop to crop. The Task Force therefore decided to develop consensus documents on phenotypic characteristics and compositional data. These data are used to identify similarities and differences following a comparative approach as part of a food and feed safety assessment. They should be useful to the development of guidelines, both national and international and to encourage information sharing among OECD member countries.

These documents are a compilation of current information that is important in food and feed safety assessment. They provide a technical tool for regulatory officials as a general guide and reference source, and also for industry and other interested parties and will complement those of the Working Group on Harmonisation of Regulatory Oversight in Biotechnology. They are mutually acceptable to, but not legally binding on, member countries. They are not intended to be a comprehensive description of all issues considered to be necessary for a safety assessment, but a base set for an individual product that supports the comparative approach. In assessing an individual product, additional components may be required depending on the specific case in question.

In order to ensure that scientific and technical developments are taken into account, member countries have agreed that these consensus documents will be reviewed periodically and updated as necessary. Users of these documents are invited to provide the OECD with new scientific and technical information, and to make proposals for additional areas to be considered.

A short, pre-addressed questionnaire is included at the end of this document. The information requested should be sent to the OECD at one of the addresses shown.

THE ROLE OF COMPARATIVE APPROACH AS PART OF A SAFETY ASSESSMENT

In 1990, a joint consultation of the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation (WHO) established that the comparison of a final product with one having an acceptable standard of safety provides an important element of safety assessment (WHO, 1991).

In 1993 the Organisation for Economic Co-operation and Development (OECD) further elaborated this concept and advocated the approach to safety assessment based on substantial equivalence as being the most practical approach to addressing the safety of foods and food components derived through modern biotechnology (as well as other methods of modifying a host genome including tissue culture methods and chemical or radiation induced mutation). In 2000 the Task Force concluded in its report to the G8 that the concept of substantial equivalence will need to be kept under review (OECD, 2000).

The Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology in 2000 concluded that the safety assessment of genetically modified foods requires an integrated and stepwise, case-by-case approach, which can be aided by a structured series of questions. A comparative approach focusing on the determination of similarities and differences between the genetically modified food and its conventional counterpart aids in the identification of potential safety and nutritional issues and is considered the most appropriate strategy for the safety and nutritional assessment of genetically modified foods. The concept of substantial equivalence was developed as a practical approach to the safety assessment of genetically modified foods. It should be seen as a key step in the safety assessment process although it is not a safety assessment in itself; it does not characterise hazard, rather it is used to structure the safety assessment of a genetically modified food relative to a conventional counterpart. The Consultation concluded that the application of the concept of substantial equivalence contributes to a robust safety assessment framework.

A previous Joint FAO/WHO Expert Consultation on Biotechnology and Food Safety (1996) elaborated on compositional comparison as an important element in the determination of substantial equivalence. A comparison of critical components can be carried out at the level of the food source (*i.e.* species) or the specific food product. Critical components are determined by identifying key nutrients, key toxicants and anti-nutrients for the food source in question. The comparison of key nutrients should be between the modified variety and non-modified comparators with an appropriate history of safe use. The data for the non-modified comparator can be the natural ranges published in the literature for commercial varieties or those measured levels in parental or other edible varieties of the species (FAO, 1996). The comparator used to detect unintended effects should ideally be the near isogenic parental line grown under identical conditions. While the comparative approach is useful as part of the safety assessment of foods derived from plants developed using recombinant DNA technology, the approach could, in general, be applied to foods derived from new plant varieties that have been bred by other techniques.

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

Wild cassava (*Manihot flabellifolia* Phol and *Manihot peruviana*) is native to tropical America (Olsen and Schaal, 2001; Chacón *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. 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, Chacón *et al.* (2008) came up with evidence suggesting that the different subspecies of *M. esculenta* are not monophyletic, most probably due to hybridizations between the cultivated crop and wild species.

Cassava is a perennial woody shrub that produces storage roots that can be harvested 6 months to 3 years after planting. It is propagated by mature woody stem cuttings, while seeds are used mainly in breeding programs. 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.

B. Production

Cassava is the fourth most important crop grown in the developing world, with global production in 2006/2007 estimated at 218 million tonnes (FAOSTAT, 2009). Cassava is used for human consumption (60% of the worldwide production), animal feed industry (33%), other industrial purposes such as textile, food, beverages (Soccol, 1996), as well as ethanol production for a short while. Cassava is a major source of energy in the tropics (Cock, 1982); based on kcal consumption per capita per day, it ranks eighth among the major food crops (FAOSTAT, 2009).

Cassava is the staple food of nearly a billion people in 105 countries, providing as much as a third of daily calories. Globally, production of cassava is expected to increase by over 50% during the period from 1993 to 2020, at an annual growth rate of around 2.5% in Africa and 1.2% in Latin America (Scott *et al*., 2000). World cassava production has increased from 188.4 million tonnes (Mt) in 2002/2003 to 217.9 Mt in 2006/2007 (Table 1). The five countries with the highest production of cassava in 2006/2007 were Nigeria (40.1 Mt), Brazil (26.6 Mt), Thailand (24.7 Mt), Indonesia (20 Mt) and the Congo Democratic Republic (15 Mt) (FAOSTAT, 2009).

Cassava is produced, mainly by small stakeholders, in the humid, sub-humid and semi-arid conditions of tropical and subtropical areas of Asia, Latin America and the Caribbean, and Africa. In 2007, the world average yield of fresh cassava roots was 11.6 t/ha, with an average of 19.1 t/h in Asia, 13 t/ha in Americas, and 8.8 t/ha in Africa. The yield varies with the cultivar, season of planting, soil type, and fertility. 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. The global estimated harvest area of cassava increased from 13.85 million hectares in 1983-1985 to 18.44 million hectares in 2006/2007 (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	96.7	101.9	110.9	111.2
Asia	47.9	49.1	51.1	53.6	57.7	70.1
Americas	28.5	31.0	31.6	32.6	35.9	36.4
Oceania	0.2	0.2	0.2	0.2	0.2	0.2
World	**132.0**	**163.5**	**179.6**	**188.4**	**204.6**	**217.9**

Source: FAOSTAT (2009)

[a] In comparing cassava and grain crops production figures, it should be noted that cassava figures are reported at 70% moisture content, while those of most grain crops are reported at approximately 15 percent moisture content.

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	7.53	10.18	11.02	11.43	11.80	11.86
Asia	3.74	3.80	3.45	3.41	3.47	3.76
Americas	2.57	2.62	2.53	2.55	2.95	2.80
Oceania	0.02	0.02	0.02	0.02	0.02	0.02
World	**13.85**	**16.62**	**17.01**	**17.41**	**18.24**	**18.44**

Source: FAOSTAT (2009)

C. Processing and Use

For the purpose of this document, cassava products are defined in Table 3.

Table 3. Terms commonly found in literature to describe parts, types and uses of cassava

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 cyanogenic potential)
Bitter cassava	Poisonous cassava variety (high cyanogenic potential)
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	Complex carbohydrate from peeled root 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	Cassava starch used in the preparation of puddings and infant feed

Source: Purdue University website, New Crop FactSHEET Cassava (1995)

1. General human and animal consumption

Sweet cassava cultivars, which contain low cyanogenic glycoside levels (<180 ppm dry weight basis), are used for human consumption, while bitter cultivars are mainly used for industrial purposes (FAO website) but can also be used for human consumption after special processing (*e.g.* "*gari*" in West Africa, or "*farinha*" in Brazil). 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). Staple food of nearly a billion people; cassava brings as much as a third of their daily calories (Eggum, 1970; Awoyinka *et al*., 1995; Tonukari, 2004; Izuagie *et al*., 2007).

Cassava tubers are valued as an energy source in human and animal diets (Babu and Chatterjee, 1999) having a carbohydrate content of about 92% (dry weight), mainly in the form of starch (Oke, 1968). Cassava roots are low in protein (Babu and Chatterjee, 1999). The leaves are also consumed and are a source of vitamin A, vitamin C, minerals (Fe, Ca) and proteins (Nweke *et al*., 2002). Cassava shoots (young stem, leaves and petioles) are also an edible source of proteins and minerals; widely used as food in Africa, they constitute a major component of the diet in the cassava growing regions (Hahn, 1992; Achidi *et al*., 2001; FAO website).

A factor limiting the human and animal consumption of cassava is its content of cyanogenic glycosides (Kakes, 1990). In the plant cells they are found in the cytoplasm and are accompanied by relatively specific hydrolytic β-glucosidases and hydroxynitrile lyase, able to degrade the cyanogenic glycosides and form bioactive toxic compounds, most notably hydrocyanic acid (HCN). However, the enzymes are sequestered from the cyanogenic glycosides and remain inactive by cellular compartmentalization to prohibit the formation of HCN at normal conditions (Conn, 1973; 1979). On cell damage the cyanogenic glycosides and the enzymes are brought in contact and HCN is formed. Cyanide (CN^-) is largely removed by traditional processing methods such as grating, fermentation, boiling or drying (Hahn, 1989). Cooking the roots inactivates the enzymes and slowly destroys the cyanogens (Nweke *et al.*, 2002). The cyanogenic potential, and dry matter content of cassava roots, as well as the pasting properties, influence the safety, and quality of processed foods and industrial products. Cassava products are rarely eaten on their own, but commonly in combination with relatively protein-rich food. However, certain processing techniques may reduce or enhance the protein, vitamin, or mineral contents of the cassava product to be consumed. Nutrients such as vitamin C are reduced during processing and cooking (Berry, 1993). Cyanogenic potential ranged from 14 to 3275 ppm in a large study including more than 4000 clones with an average of 327 ppm (Sánchez *et al*., 2009).

Post-harvest physiological deterioration often begins within 24-48 hours after harvest and quickly spoils the roots (Beeching *et.al.*, 1998). It is not a microbial process but a self-inflicted reaction by genes active in the root. 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. Chávez *et al*. (2005) studied the association between carotene content and post-harvest physiological deterioration and obtained a negative correlation, although further study is still required.

Processing of cassava leaves has a marginal effect on the majority of the compositional nutrients. In a study by Achidi (2003), 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 the levels of free sugars, ascorbic acid, thiamine, cyanogenic potential, and tannin levels. Ravindran *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. These processing methods had little influence on the crude protein

content of leaf meal, except chopping of leaves which resulted in consistently reduced crude protein content. The mean crude protein level was 23.1 g/100 g dry matter.

Fasuyi (2005) studied the nutrient profile of 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 level of protein and several minerals (Ca, Zn, Ni and K) were found to be high.

2. Human food processing

Cassava is consumed by humans as fresh processed roots, fermented roots, cassava flour-based products or cooked leaves. Traditionally, roots and leaves are processed by diverse methods on the different continents, offering a range of food products which include dried cassava chips, flour used for a variety of baked products and snacks, etc. Fresh cassava roots can be frozen, fried or boiled (Agrocadenas website; Cook, 1985; Cereda, 2003; Howeler, 2004; Embrapa, 2005).

Cassava processing involves a combination of step-wise activities, including (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 the final product. Some of the processed products can be eaten without further cooking, while others require some extra preparation (Nweke, 1990). The most commonly used processing methods are presented in Figure 1.

The most important processed product of cassava is fermented ("bitter") starch, which on a dry weight basis (12% moisture) consists of 96% carbohydrates and 3% proteins. The starch is good for making bread, because it expands during baking. Fermented 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) in Brazil (Agrocadenas website). Another product, cassava flour, can be used as a substitute (up to 30%) for wheat flour in baking (Grace, 1977, on FAO website)

3. Animal feed processing

All cassava varieties can be used in animal feed, but it is necessary to process them because of the presence of cyanogenic glycosides, otherwise hydrolysis of the cyanogenic glycoside linamarin, would form HCN. Less than 100 g HCN/ kg cassava product is considered as acceptable for animal feed.

Cassava leaves and roots are a useful alternate energy source for animal production. Fresh cassava foliage for a balanced animal feed has potential and could be as high as 100 tonnes per ha per year depending on fertility of soil and rainfall (Ospina *et al*., 2002). 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 (Chauynarong *et al*., 2009). The moisture content has to be reduced when forage is used for silage production. Based on experiences and data collated in different countries, CIAT-Colombia established formula for silage shown in Table 4. Addition of nitrogen (usually in the form of urea) is recommended when roots constitute an important share of the silage formula. Fermentable carbohydrates brought with added molasses (or with other added sources such as corn meal, see Ubalua, 2007) can facilitate rapid fermentation, especially when forage is the main silage component.

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

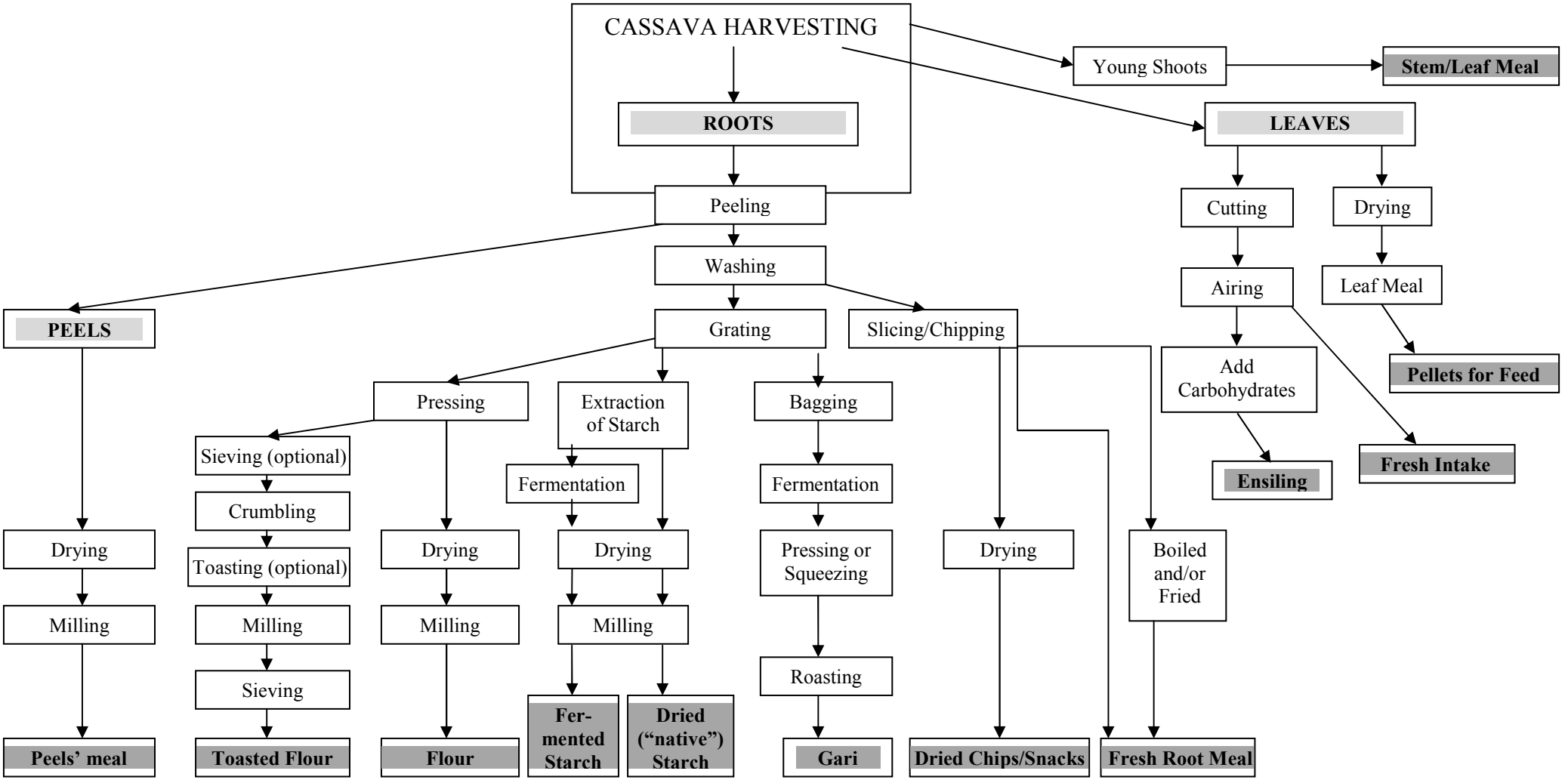


Table 4. Formula for silage from different sources

Silage component	Content (%)			
Cassava forage	80.0	65.5	92.0	
Cassava roots	20.0	33.0		98.2
Urea		1.5		1.8
Molasses *(or corn meal)*			8.0	
Total	100.0	100.0	100.0	100.0

Source: CIAT (unpublished data)

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

Solid wastes produced from cassava processing –comprising peelings from initial processing, fibrous by-products from crushing and sieving, and starch residue after starch settling– require specific management practices for their use as feed (Sackey and Bani, 2007; Chauynarong *et al*., 2009). Peels are used for animal feed after adequate fermentation in many South American, African and Asian countries; cassava peels are also reported as a medium for mushroom cultivation and to produce compost. Protein enrichment of cassava wastes by development of micro-organisms can provide high quality feedstuffs (Ubalua, 2007). The fibrous residual material, constituting around 30% of the original tubers, forms the cassava pulp left after starch extraction; dewatered in a screen press and dried in a flash dryer, it is sold to the feed industry (TIMEIS India, 2005). Solid residues can also be ensiled. The ensiling process contributes to lower the cyanide level to a non-toxic level thus reducing the pH to about 4.0 and allowing lactic acid to build up, and the product can be used as animal feed (Sackey and Bani, 2007).

4. Range of food products and other industrial outputs

Modified starch derived from cassava can be used widely in the food industry. Cassava starch has unique properties such as high viscosity and resistance to freezing. Industrial markets include those for unmodified starch for glucose products used in food binders and thickeners, and for animal feed. There is also great potential for cassava starch utilisation in the sweetener and alcoholic beverages industries. Large volumes of "native" or modified cassava starches are used for many different non-food industrial uses, such as in the paper and textile industry.

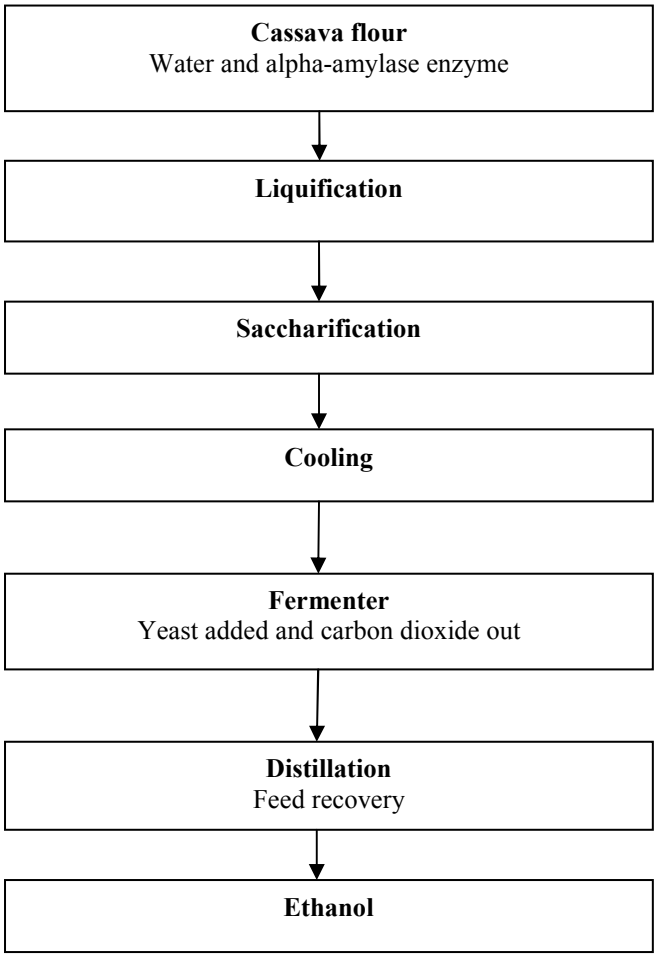
5. Ethanol production and animal feed by-products

Apart from its traditional role as a food crop, cassava can be used as a carbohydrate source to produce ethanol which is used by the pharmaceuticals and beverages industry (TIMEIS India, 2005). It has become an important crop for bio-fermentation in Brazil, Thailand, China and countries in Sub-Saharan Africa, especially Nigeria. In a series of steps, starch is converted to glucose that is then fermented to produce ethanol. A flowchart showing the process is depicted in Figure 2 (IITA cassava project website). However recent technological developments are simplifying the process to produce ethanol from starchy crops by merging some of the stages detailed in Figure 2 (Chamsart *et al.*, 2007).

The cassava pulp (solid waste resulting from starch extraction) is also considered by some studies as a potential source for low-cost ethanol production (JIRCAS, 2006).

In addition to ethanol production, the manufacturing process provides for marketable feed by-products, e.g. cassava cake and bagass (Suthsmma and Sorapipatana, 2007). Selling these by-products to the feed industry is an important economic outlet for ethanol manufacturers.

Figure 2. Schematic presentation of the ethanol production process from cassava



Source: IITA – Integrated Cassava Project website

D. Appropriate comparators for testing new varieties

This document suggests parameters that cassava breeders should measure when developing new modified varieties. The data obtained in the analysis of a new cassava variety should ideally be compared to those obtained from an appropriate near isogenic non-modified variety, grown and harvested under the same conditions.[1] The comparison can also be made between values obtained from new varieties and data available in the literature, or chemical analytical data generated from other commercial cassava varieties.

[1] For additional discussion of appropriate comparators, see the Guideline for the Conduct of Food Safety Assessment of Foods Derived from Recombinant DNA Plants CAC/GL 45/2003 of the Codex Alimentarius Commission (paragraphs 44 and 45).

Components to be analysed include key nutrients, toxicants and allergens. Key nutrients are those which have a substantial impact in the overall diet of humans (food) and animals (feed). These may be major constituents (fats, proteins, and structural and non-structural carbohydrates) or minor compounds (vitamins and minerals). Similarly, the levels of known anti-nutrients and allergens should be considered. Key toxicants are those toxicologically significant compounds known to be inherently present in the species, whose toxic potency and levels may impact human and animal health. Standardized analytical methods and appropriate types of material should be used, adequately adapted to the use of each product and by-product. The key components analysed are used as indicators of whether unintended effects of the genetic modification influencing plant metabolism has occurred or not.

E. Breeding characteristics screened by developers

About ninety eight species of genus *Manihot* are recognized. Cultivars have been developed through domestication of natural hybrids of wild species and maintained through vegetative reproduction (Allen, 1994). 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 content, and reduced cyanogenic glycoside levels. Cassava varieties exist that are either "bitter" (high in cyanogenic glycosides) or "sweet" (low in cyanogenic glycosides) 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. Genetic engineering can provide an alternate means for developing improved or novel varieties (Taylor *et al*., 2004). For example, transgenic cyanogen-free cassava has been developed (Siritunga and Sayre, 2003), and a storage protein (ASP1) has been expressed in cassava (Zhang *et al.,* 2003).

SECTION II – NUTRIENTS

The range of mean values for the nutrient composition of cassava roots, leaves and processed cassava products are shown in Tables 5 to 21.

A. Unprocessed roots and leaves

1. Proximate composition

Representative data on nutrient composition of fresh cultivated cassava roots and leaves are presented in Tables 5 and 6, respectively. In some studies only average values are presented. When available, the variation in each parameter, as indicated by the minimum and maximum values, is given. The variation in values can be attributed to genetic, agricultural and environmental factors. Thus, the composition of fresh cassava roots and leaves varies with cultivar/variety, age of the plant tissue, geographical location, agricultural conditions, and climate (Fasuyi and Aletor, 2005). For example, in six cassava varieties from South Vietnam, India and Japan, cassava leaves were shown to vary substantially in composition, *viz.* (g/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 (Nhu Phuc *et al.*, 2000; Table 6). 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.

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).

A wide variation in moisture content of roots has been reported. Bradbury and Holloway (1988) reported an average moisture content of 62.8 g/100g (fresh weight basis) for roots, while a range of 56.4 g to 76 g/100 g sample was reported by Yeoh and Truong (1996). Using the specific gravity method, Chavez *et al*. (2005) measured the moisture content of 2022 root samples collected from all over the world. The dry matter (DM) values ranged from 10.7 to 57.2 g/100 g fresh sample weight, with a mean of 34.3 g/100 g sample. Sanchez *et al*. (2009) recently reported a range of DM content (from 4000 genotypes) of cassava roots from 14.3 to 48.1%. The DM content is not presented in 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.

Bradbury and Holloway (1988) reported an average moisture content of 74.8 g/100 g sample (fresh weight basis) for leaves. A study on young cassava leaves obtained from 19 different cassava varieties, showed that the DM content of this plant tissue ranged from 23 to 27.8%. (Achidi, 2003), while Gomez and Valdivieso (1984) recorded dry matter values between 30.8 and 35.7 g/100 g in leaves (plus petioles) harvested at 9-12 months after planting.

Table 5. Proximate composition of fresh cassava roots [a]

References	**Akinfala *et al.*, 2002**	**USDA 2008** [b]	**FAO, 2001** [c]	**Ogunti-mein, 1988**	**Tien Dung *et al.*, 2005**	**Smith, 1988**	**Range of mean values**
	(g/100 g of dry matter)						
Crude protein	4.7	3.4	1.9	2.0	2.4	1.5-3.5	1.5–4.7
Crude fibre	2.1		0.8	4.0		1.3-7.7	0.8-7.7
Total dietary fibre		4.5					4.5
Crude fat [d]	2.5	0.7	0.3	0.7	2.2	0.8-3.2	0.3-3.2
Ash	8.4	1.5	0.5	5.0	1.5	1.6-4.1	0.5-8.4
NFE [e]	75.3	(94.4 [h])	56.0	75.5		88.0-94.1	56.0-94.1
NDF [f]					5.5		5.5
ADF [g]					2.5		2.5

[a] It is assumed the roots were not peeled (not always reported).
[b] The data was converted to a dry matter basis, using the level of water content of 59.68 g/100 g given in the USDA table.
[c] FAO (2001), Table "Proximate Composition of Food"
[d] Ether extractable fat
[e] Nitrogen free extract
[f] Neutral detergent fibre
[g] Acid detergent fibre
[h] USDA lists this value as carbohydrate, by difference.

Table 6. Proximate composition of fresh cassava leaves

References	**Akinfala *et al.*, 2002** [a]	**Nhu Phuc *et al.*, 2000** [b]	**Ogunti-mein, 1988**	**Smith, 1988**	**Hang and Preston, 2005**	**Range of mean values**
	(g/100 g of dry matter)					
Crude protein	18.0	23.9-34.7	24.1	14.7-36.4	20.0 -30.01	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 [c]	43.3	31.7-45.5 38.8	39.9	31.7-45.5	44.2	31.7-45.5
NDF [d]					29.6	29.6
ADF [e]					24.1	24.1

[a] Composite sample prepared for trial
[b] Average of 6 cultivars, sun-dried
[c] Nitrogen free extract
[d] Neutral detergent fibre
[e] Acid detergent fibre

Crude protein is widely determined using the Kjeldahl technique, in which the nitrogen content is measured and multiplied by 6.25 to estimate crude protein. In cassava, and possibly other crops, not all the nitrogen is incorporated in proteins. Differences in genetics (germplasm) and growth conditions create huge variations in free amino acids and non-protein nitrogen (Yeoh and Truong, 1996). Chavez *et al*. (2005) analysed the roots (assumed unpeeled) of 600 cassava genotypes collected world-wide and reported a mean crude protein content of 3.06 g/100 g DM, ranging from 0.77 g to 8.31 g/100 g dry matter. Ceballos *et al*. (2006) searched for varieties containing high protein levels and reported (using a conversion factor of 6.25 to go from total nitrogen to crude protein) a crude protein content ranging between 0.95 and 6.42 g/100 g DM. These investigators also measured the HCN produced in the cassava and found no correlation between HCN content and crude protein content, perhaps because most of the HCN is removed from the plant in sample preparation. Fifteen cassava varieties from Asia showed a lower root protein content ranging from 0.5 to 1.9 g/100 g DM (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 world-wide (Table 5) have a lower level of crude protein in the roots (1.5 to 4.7/100 g DM) (Babu and Chaterjee, 1999; Ceballos *et al*., 2006). *Note: Preliminary data from CIAT would suggest that the N-to-protein conversion factor is considerably lower than the standard value of 6.25. A reliable and relatively simple method for a direct quantification of total soluble proteins based on Bradford's approach would be much more precise that indirect quantification based on N.*

The crude protein content of leaves of cassava ranges between 14.7 to 36.4 g/100 g dry matter (Table 6).

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 DM (Table 5). However, the leaves contain relatively high levels of fat, ranging from 4.0 to 15.6 g/100 g DM (Table 6).

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 matter in the samples. For cassava roots, ash varies between 0.5 and 8.4 g/100 g DM, and is higher in leaves, ranging between 5 and 16.1 g/100 g dry matter (Tables 5 and 6). The extent to which variation is due to soil contamination is not clear, because in some references it was stated explicitly 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 10 g/100 g DM according to studies conducted by Eggum (1970) and Luyken *et al.* (1961).

Nitrogen free extract (NFE), representing the non-fibre carbohydrates, is usually determined by difference (moisture, fat, ash, crude fibre and proteins are measured and the remainder is attributed to NFE) and constitutes a heterogeneous complex of compounds, including the starch. NFE levels in cassava roots vary considerably depending on the cultivar, ranging between 56 to 94 g/100 g DM (Table 5). In addition, peeling of roots may have an effect on the proportion of proximates, since non-fibre carbohydrates are present in the roots. Leaves contain lower levels of NFE than roots, ranging between 31.7 and 45.5 g/100 g DM (Table 6).

Cassava normally contains 0.8-7.7 g/100 g dry weight crude fibre, a component that reduces its digestibility. Digestibility is important in both human and animal cassava-based diets. Excess fibres interfere with the utilization of phosphorous and zinc (Oke, 1978). The crude fibre content, like the 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). Fresh leaves have a high fibre content (average of 17 g /100 g dry weight), and digestibility is low (70-80% in young leaves, decreasing to 67% in old leaves) (Eggum, 1970; Luyken *et al*., 1961).

Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (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 6 and 7).

2. Carbohydrates

Cassava roots are a good source of energy, with carbohydrate contents reported as high as 91% on a dry weight basis (Oke, 1968; Sanchez *et al*., 2009). Szylit *et al*. (1978) determined that cassava roots contained 74.7 g starch/100 g DM and 0.6 g ethanol-soluble carbohydrates/100 g DM and a mean starch granule diameter of 12 μg. On average 73-85% of dry root weight of cassava is starch (Rickard *et al*., 1991). Starch content varies in different cassava germplasm, such as improved clones and landraces (Sanchez *et al*., 2009). The high starch content ranging from 18-24% amylose and 70% amylopectin makes for ideal digestion (Johnson and Raymond, 1965). 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). Average amylose content in starch from a large sample of cultivars was 20.7% (Sánchez *et al.*, 2009) and can be used as a standard reference point. Amylose-free natural mutation and induced mutation for high-amylose (36%) cassava starch have been reported (Ceballos *et al*., 2007; 2008). Amylose-free starch is easily digestible and better for ethanol production. High-amylose can lead to the production of resistant starches which have distinctive advantage in health, particularly in diabetes management and stimulation of butyrate production in the large intestine that has been found to be beneficial to colon health (Jobling, 2004; Lehman and Robin, 2007).

The metabolisable energy of cassava roots varies with the genotype (variety), age of the root, harvesting time, and climatic conditions, and is also dependent on method of processing. Differences might also be due to the state of processing of cassava, the raw sample having a digestibility of about 48.3% and the cooked 77.9%. The higher amylopectin content of cassava relative to maize makes it a more suitable source of energy for ruminants than for monogastric animals (Oke, 1978). Analysing 1755 samples, Chávez *et al.* (2005) recorded an average total root sugar content of 8.4 g/100 g DM and an average content of reducing sugars of 2.2 g/100 g DM, while Sanchez *et al*. (2009) reported total and reducing sugars in cassava roots ranging from 0.2 to 18.8% and 0.0 to 15.7%, respectively, on a dry weight basis. A group of interesting "sugary" mutations in cassava that result in storage roots with high free sugars (mostly glucose) and a glycogen-like molecule was reported by Carvalho and co-workers in 2004. The roots from these genotypes have reduced levels of amylose.

A study by Nhu Phuc *et al.* (2000) on leaves of six cassava varieties from South Vietnam, India and Japan showed that the free sugars range varied from 2.2 to 4.4 g/100 g DM, starch from 4.7 to 6.1 g/100 g DM, 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 DM.

3. True protein (amino acids)

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 cyanogeic glycosides. The traditional formula for calculation of crude protein (nitrogen measured by Kjeldahl method and multiplied by 6.25) therefore overestimates the true protein content. Based on analysis of crude protein content of 15 varieties of cassava roots, Yeoh and Truong (1996) estimated that 51 to 75% of the nitrogen in cassava roots consists of true protein, i.e. nitrogen incorporated as protein-associated amino acids.

The amino acid composition of the true protein in cassava roots, as well as the concentration of individual amino acids per 100 g DM, is presented in Table 7. However, the latter will depend on the concentration of true protein per 100 g DM. In Table 7 the mean values reported in the two studies on cassava roots were 0.404 and 0.827 g/100 g DM, while that of the individual cultivars analysed by Nassar and Vale de Sousa (2007) varied between 0.255 and 1.654 g/100 g DM.

Cassava leaves are rich in proteins and essential amino acids. Studies have shown a range of leaf protein content of 29.3 to 38.6 g/100 g DM (Yeoh and Chew, 1976). Nhu Phuc *et al*. (2000) analysed leaves from 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. The amino acid composition of leaf protein (g per 100 g protein) (Eggum, 1970; Devendra, 1977; Cereda, 2001) is presented in Table 8.

Table 7. Amino acid composition in the protein of cassava roots

References	**Nassar & Vale de Sousa, 2007**	**Oke, 1978**	**USDA, 2008** [a]	**Range of mean values**
	(g/100g dry sample powder)			
Arginine	0.145	0.178	0.340	0.145-0.340
Histidine	0.020	0.034	0.050	0.020-0.050
Isoleucine	0.031	0.046	0.067	0.031-0.067
Leucine	0.055	0.064	0.097	0.055-0.097
Lysine	0.043	0.067	0.109	0.043-0.109
Methionine	0.019	0.022	0.027	0.019-0.027
Phenylalanine	0.065	0.041	0.064	0.041-0.065
Threonine	0.030	0.043	0.069	0.030-0.069
Tryptophan	-	0.019	0.047	0.019-0.047
Valine	0.056	0.054	0.087	0.054-0.087
Alanine	0.048		0.094	0.048-0.094
Aspartic acid	0.068		0.196	0.068-0.196
Cystine	0.026	0.023	0.069	0.023-0.069
Glutamic acid	0.124		0.511	0.124-0.511
Glycine	0.038		0.069	0.038-0.069
Proline	0.020		0.082	0.020-0.082
Serine	0.040		0.082	0.040-0.082
Tyrosine	0		0.042	0.000–0.042
AA/100 g DM	0.827	0.404	2.103	0.404-2.103

[a] The data was converted to a dry matter basis, using the level of water content of 59.68 g/100 g given in the USDA table.

Table 8. Amino acid composition in the protein of cassava leaves and meal

References	**Eggum, 1970** [a]	**Devendra, 1977** [b]	**Cereda, 2001** [c]	**Range of mean values**
	(g/100 g protein)			
Arginine	4.0 – 5.7	5.1		4.0 – 5.7
Histidine	1.1 – 2.5	2.7	2.2	1.1 – 2.7
Isoleucine	3.9 – 5.0	4.3	5.0	3.9 – 5.0
Leucine	7.2 – 8.9	4.7	9.1	4.7 – 9.1
Lysine	3.8 – 7.5	7.1	6.3	3.8 – 7.5
Methionine	1.3 – 2.0	1.1	(4.8 [1])	1.1 – 2.0
Phenylalanine	5.3 – 5.4	3.6	(8.8 [2])	3.6 – 5.4
Threonine	3.2 – 5.0	4.7	4.8	3.2 – 5.0
Tryptophan	2.0	1.0		1.0 – 2.0
Valine	5.1 – 5.7	6.4	6.4	5.1 – 6.4
Cystine	0.7 – 1.4	1.0		0.7 – 1.4
Glycine		4.6		4.6

[a] Leaves
[b] Meal
[c] Dried leaves
[1] Methionine + cystine
[2] Phenylalanine + tyrosine

4. Lipids

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 9. Polar lipids plus sterols and steryl esters constitute the major portion (77.9%) of the extracted lipids. Of the seven phospholipids identified, phosphatidylcholine occurred in the highest concentration (265.4 nmol/g fresh weight), while of the six glycolipids identified, digalactosyldiacylglycerol was the most abundant glycolipid (333.2 nmol/g fresh weight). Free sterols averaged 304.3 nmol/g fresh weight and triacylglycerol was measured at 444.4 nmol/g fresh weight. 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. 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 9. Lipid composition of cassava roots (fresh weight)

Lipid	**nmol/g fresh weight** [a]
Total phospholipids	706.0
Total glycolipids	818.6
Total neutral lipids	892.6

Source: Lalaguna and Agudo (1988)
[a] The concentrations are not converted to dry weight because the lipids are presented as lipid combinations.

The major fatty acids of cassava root meal lipid are oleic and palmitic acids. The other fatty acids found in raw cassava roots are linoleic, linolenic, palmitoleic, stearic, myristic, pentadecanoic, heptadecanoic and nonadecanoic acids (Ezeala, 1985). The fatty acid composition of raw cassava roots is summarized in Table 10. Fermentation of processed roots of cassava 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 illustrates fatty acid composition of fermented and unfermented cassava tuber meal.

Table 10. Fatty acid composition of raw cassava roots

Fatty Acid	g per 100g dry matter [a]
Palmitic acid (16:0)	0.17
Stearic acid (18:0)	0.01
Oleic acid (18:1)	0.19
Linoleic acid (18:2)	0.08
A-Linolenic acid (18:3)	0.04

Source: USDA (2008)

[a] The data was converted to a dry matter basis, using the level of water content of 59.68 g/100 g given in the USDA table.

Table 11. Fatty acid composition and content of unfermented and fermented cassava tuber meal

	Fatty acid (g/kg dry tuber meal) [a]		Fatty acid (% total fatty acid) [a]	
Fatty acid	**Unfermented**	**Fermented**	**Unfermented**	**Fermented**
Myristic acid (14:0)	0.06	0.08	1.2	1.2
Pentadecanoic acid (15:0)	0.03	0.06	0.6	0.9
Palmitic acid (16:0)	1.50	2.10	31.0	31.4
Palmitoleic acid (16:1)	0.20	0.22	4.1	3.3
Margaric acid (17:0)	0.02	0.03	0.5	0.5
Stearic acid (18:0)	0.13	0.34	2.7	5.2
Oleic acid (18:1)	1.80	2.46	37.5	37.2
Linoleic acid (18:2)	0.70	1.02	14.5	15.4
A-Linolenic acid (18:3)	0.38	0.30	7.9	4.6
Nonadecanoic acid (19:0)	tr. [b]	0.02	tr. [b]	0.3

Source: Ezeala (1985)

[a] Means of three different determinations

[b] Trace

5. Minerals

The mineral content of cassava roots and leaves is shown in Tables 12 and 13, respectively. In addition, FAO gives the calcium and iron content of processed root flour as 0.74 g/kg dry matter and 4.0 mg/g dry matter, respectively. Evaluations by CIAT of Iron and Zinc contents in cassava roots found some genetic variation, with average values of 15.7 and 6.35 mg/kg (dry weight basis) respectively. Quantification for these two elements can result from Fe and Zn contaminations coming from the soil attached to the roots. The PH of the soil where the cassava was planted was found to have a high impact on Fe and Zn contents in roots (CIAT, 2005).

Hung Nguyen *et al*. (2002) tested the influence of different levels of NPK fertilizer on the mineral 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 the concentrations of N, P, K, S, Mn and Cu in cassava leaves, while the concentrations of Mg and Ca were reduced.

Table 12. Minerals composition of cassava roots

References	**FAO, 2009**	**USDA, 2008** [a]	**Chavez *et al.*, 2005**	**Range of mean values**
Mineral	(g /kg dry matter)			
Calcium	1.1	0.40	0.31-2.5	0.31-2.5
Phosphorus		0.67	0.71-3.2	0.67-3.2
Magnesium		0.52	0.52-2.4	0.52-2.4
Potassium		6.72		6.72
Sodium		0.35	0.02-1.23	0.02-1.23
	(mg/kg dry matter)			
Iron	3.0	6.70	6.0-230.0	3.0-230.0
Manganese		9.52	0.45-5.0	0.45-9.52
Copper		2.48	0.79-40.3	0.79-40.3
Zinc		8.43	2.63-37.5	2.63-37.5
Aluminium			4.4-330	4.4-330
Selenium		0.02		0.02

[a] The data was converted to a dry matter basis, using the level of water content of 59.68 g/100 g given in the USDA table.

Table 13. Mineral composition of dried cassava leaves and processed leaf meal

References	**Dried Leaves**			**Dried Leaf Meal**		
	Cereda, 2001	**Hung Nguyen *et al.*, 2002** [a]	**Range of mean values**	**Yousuf *et al.*, 2007**	**Vongsam-phanh & Wanapat, 2004**	**Range of mean values**
	(g/kg dry matter)			(g/kg dry matter)		
Calcium	16	3.6-6.2	3.6-16	17.4	9.2	9.2-17.4
Phosphorus	2.9	1.6-2.8	1.6-2.9	3.6	3.0	3.0-3.6
Magnesium	3.8	2.0-4.1	2.0-4.1			
Potassium	10	9.5-22.3	9.5-22.3			
Sodium		-				
Sulphur	2.4	3.0-3.8	2.4-3.8			
	(mg/kg dry matter)			(mg/kg dry matter)		
Iron	442	800-2000	442-2000		16.1-2000	16.1-2000
Manganese	351	140-200	140-351		12.9-200	12.9-200
Copper	6	5.5-7.4	5.5-7.4		3.6-17.7	3.6-17.7
Zinc	40	61-81	40-81		8.4-81.0	8.4-81.0

[a] Fully expanded leaves, third and fourth from the top four months after planting

6. Vitamins

Vitamin levels in mature cassava roots and leaves are low, with pro-vitamin carotenes being the most important constituent. Total carotene levels in roots vary widely amongst cassava cultivars/varieties (Iglesias *et al.*, 1997). A study by Chavez *et al.* (2005) of 1789 accessions from the CIAT germplasm bank showed a range of total carotene in roots from 1.02 to 10.4 µg/g fresh weight, with an average of 2.457 µg/g fresh weight (7.17 µg/g dry weight). Maximum levels of total carotenoids in breeding populations range between 15-18 µg/g (fresh weight basis) and maximum levels of total β-carotene range between 12-13 µg/g also on a fresh weight basis (CIAT, 2009). FAO figures showed low levels of total carotene in roots of bitter cassava of 0.24 mg/kg DM. Among vitamins, ascorbic acid (vitamin C),

thiamine, riboflavin and niacin are most important. Again these vary according to the cultivar and age of the cassava plants (Table 14). Cassava leaves, however, are rich in vitamins, especially the young leaves that are usually eaten by humans (Awoyinka *et al*., 1995); in a study by Nhu Phuc *et al.* (2000), the leaves of six cassava varieties from South Vietnam, India and Japan were found to be rich in ascorbic acid, thiamine and β-carotene.

Table 14. ß-carotene and vitamin content of cassava roots and flour

		Root			Flour
References	**Unit**	**FAO, 2001**	**USDA, 2008** [a]	**Range of mean values**	**Grace, 1977 (FAO)**
		(per kg dry weight)			
Provitamin A [β-carotene]	(mcg)	24	198	24-198	0
Vitamin B_1	(mg)	48	2.16	2.16-48	
Vitamin B_2	(mg)	0.06	1.19	0.06-1.19	0.07
Vitamin B_6	(mg)	0.08	2.18	0.08-2.18	0.06
Niacin	(mg)	0.9	21.18	0.9–21.18	0
Folic acid	(µg)	38		38	
Folate	(mcg)		669.64	669.64	
Vitamin C	(mg)	50	510.91	50-510.91	4.5

[a] The data was converted to a dry matter basis, using the level of water content of 59.68 g/100 g given in the USDA table.

B. Processed cassava products

Table 15 illustrates the proximate composition of cassava peel meal, cassava meal and flour. Cassava tapioca and starch contain an average of 0.50 g protein and 0.33 g fat/100 g dry matter.

Table 15. Nutrient composition of processed cassava roots

	Peel meals			Cassava meal				Root meal	Flour
References	**Salami, 2000**	**Osei *et al*., 1990**		**FAO, 2001**	**Sable *et al*. 1992**	**Kozloski *et al.* 2006**	**Range of mean values**	**An *et al*., 2004**	**Aregheore *et al*. 1988**
		Unfer-mented	**Fer-mented**						
	(g/100g dry matter)			(g/100g dry matter)				(g/100g dry matter)	
Crude protein	5.9	5.1	5.3	1.8	2.6	1.6	1.6-3.2	2.9	3.2
Crude fibre	13.4	11.3	11.5	0.5			0.5-6.3	3.2	6.3
Fat [a]	1.2	0.8	0.7	0.6		0.3	0.3-1.9	1.9	0.8
Ash	10.8	4.9	9.3	0.3	0.8		0.3-1.8	1.7	1.8
NFE [b]	68.9	67.4	63.9	92		87.7 [1]	83.8-92.0		83.8 [2]
NDF [c]					3.1	9.8	3.1-9.8	9.3	
ADF [d]					1.8	3.0	1.8-3.6	3.6	

[a] Ether extractable fat
[b] Nitrogen free extract
[c] Neutral detergent fibre
[d] Acid detergent fibre
[1] Non-fibre carbohydrates
[2] Starch. Peeled tubers

The proximate composition of processed cassava leaves and cassava hay is presented in Table 16. Processed leaves are used in the feeding of monogastric animals such as pigs and poultry (Nhu Phuc *et al*., 2000; Du and Preston, 2005) as well as for ruminants, while the foliage (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 to stems, the latter having a lower protein content (Tien Dung *et al*., 2005).

Table 16. Proximate composition of processed cassava leaves and foliage

	Leaves (g/100 g dry matter)			**Foliage** [a] (g/100 g dry matter)				
References	**Nhu Phuc *et al*., 2000**		**Yousuf *et al*., 2007**	**Kiyothong & Wanapat, 2003**	**Wanapat *et al*., 1997**	**Vongsamphanh & Wanapat, 2004**	**Tien Dung *et al*. 2005**	**Range of mean values**
	Silage	**Meal**	**Meal**	**Hay** [b]	**Hay**	**Hay** [c]	**Hay**	
Crude protein	27.6	26.0	26.8	20.6	24.9	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	8.0	10.7	6.6-10.7
NFE [d]	31.1	37.1					39.5	39.5
NDF [e]	33.5	33.5	26.1	55.0	34.4	67.7	29.7	29.7-67.7
ADF [f]			13.4	38.9	27.0	41.7		27.0-41.7
ADL [g]				16.8	3.8	13.2		3.8-13.2

[a] Leaves, stems and petiole
[b] Whole plant at 3 months after planting
[c] Harvested at 3, 5 and 7 month
[d] Nitrogen free extract
[e] Neutral detergent fibre
[f] Acid detergent fibre
[g] Acid detergent lignin

Table 17 shows the moisture and protein contents, and amount of metabolizable energy in fresh cassava roots and various cassava products and by products used in animal feed.

Table 17. Moisture, protein and energy content of cassava products/by-products used in animal feed

Products and by-products	**Moisture** %	**Metabolizable Energy** (Kcal/g) -dry weight-	**Crude Protein** % -dry weight-
Fresh roots	65	3.7	1.5-3.5 [a]
Root silage	60	3.5	3.5
Dried roots	13	3.6	3.5
Fresh foliage	72	1.1	21.8
Foliage silage	68	1.3	20.0
Foliage dry	13	1.3	25.3
Fresh bran	90	5.0	9.0
Dry bran	13	2.6	3.3
Mancha fresca	90	5.0	8.0
Mancha seca	13	3.1	3.2

Source: Ceballos and Ospina, (2002)
[a] From Table 5

SECTION III – OTHER CONSTITUENTS

A. Anti-nutrients

1. Tannins

Tannins are considered anti-nutrients because they can interfere with the absorption of iron and other minerals as well as precipitate dietary proteins potentially rendering them indigestible (Brune *et al*., 1989). Tannin concentrations are negligible in roots and also are low in fresh or dry leaves from most cassava varieties (Achidi, 2003; Rickard, 2006). In leaves, the highest tannin level (29.7 g/kg dry weight) has been found in fresh red cassava leaves (Awoyinka *et al*., 1995). After drying, tannin levels decline rapidly to a range of 2 to 3 g/kg dry matter (Table 18). Cassava leaves also contain complexes between tannins and proteins (Wanapat, 1995). Reed *et al*. (1982) showed that the processing of the cassava leaf affects the tannin content.

Vongsamphanh and 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 and 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 and Wanapat (2004) and Tien Dung *et al.* (2005) used the vanillin-HCI method for condensed tannin.

Table 18. Tannin content (Vanillin-HCl assay) of cassava leaf meal as influenced by processing methods

	Oven-drying (g/kg dry matter)		**Sun-drying** (g/kg dry matter)	
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

The anti-nutritional effect of phytic acid (phytin or inositol hexakisphosphate), a phosphate-rich cassava constituent, 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 phytic acid so that phosphorus can be released for metabolism. When a high proportion of the phosphorus present in the feed occurs as the poorly digestible phytic acid, a considerable amount of dietary phosphorus may be voided in faeces. Reed *et al*. (1982) have reported a phytic acid content of between 107 and 249 mg/100 g sample in fresh unprocessed leaves of different varieties. The authors also showed that processing of cassava leaves affects the phytic acid content considerably.

Charles *et al*. (2005) found 95-136 mg per 100 g of phytic acid in five varieties of peeled cassava roots. Favaro et al. (2008) found 258-365 mg phytic acid per 100 g dry weight in two varieties of peeled cassava roots.

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

Wobeto *et al.* (2007) studied the levels of several anti-nutrients in leaf meal of five different cultivars of cassava appropriate for human consumption at three different maturity stages of growth –12, 15 and 17 month old plants. The oxalate levels were lowest in the 12 month old plants, except for the cultivars Ouro do Vale and Maracanã. Nitrate levels decreased with maturity of the plant. Table 19 shows the polyphenol (tannin) content, and trypsin inhibitor and saponin activity of the five analysed cultivars. In general, the polyphenol content increased with the maturity of the plant. The polyphenol contents found in cassava leaf meal have been reported to vary from 2.1 to 120mg/100 g dry matter (Wobeto *et al*., 2007).

Table 19. Average polyphenol and trypsin inhibitor content, and saponin in activity in cassava leaf meal at three ages of the plant

	Polyphenol (mg/100g dry matter)			**Trypsin inhibitor** (mg/100g dry matter)		
Cultivars	**12 mo** [a]	**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	2.43	2.95
Mocotó	44.13	78.86	79.88	0.57	3.13	3.28
	Saponin (g/100g 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			

Source: Wobeto et al. (2007)

[a] Months (mo)

B. Toxicants

The cassava plant produces two cyanogenic glycosides, linamarin and lotaustralin, in the edible portion of its roots and leaves. Linamarin is stored in the vacuoles of leaf and root cells. On stress, linamarin is released from the vacuole and interacts with the cell wall-localized enzyme linamarase which deglycosylates linamarin yielding acetone cyanohydrin, the precursor of cyanide (HCN) (Mkpong *et al*., 1990). Linamarin is synthesized in leaves and is transported to roots where it serves as a source of N for protein synthesis. Levels of linamarin in the roots vary between 15-500 mg CN equivalents/kg fresh weight while levels in leaves vary less and are higher at 200-500 mg CN equivalents/kg fresh weight (Mkpong *et al*., 1990; Haque and Bradbury, 2004). In addition to linamarase, cassava leaves have hydroxynitrile lyase (located in the cell wall) that converts acatone cyanohydrin into cyanide. At small doses, cyanide is detoxified to thiocyanate by means of the enzyme rhodanase, which use methionine that becomes the first limiting amino acid in cassava feed.

The amounts of cyanogenic glycosides vary considerably, according to cultivar and growing conditions, and the cyanogenic potential, therefore, varies greatly between studied varieties (Achidi, 2003), Roots frequently contain 10–500 mg CN equivalents/kg dry weight, and leaves 200–1300 mg CN equivalents/kg dry weight. Chavez *et al.* (2005) reported an average of 263.7 (range 13.9-2561.7) mg/kg dry weight HCN in cassava roots from cultivars in the CIAT breeding program (Sanchez *et al*. , 2009). This implies that for many cassava varieties the cyanogenic potential results in levels exceeding the maximum recommended cyanide level in foods (10 mg CN equivalents/kg dry weight) established by the FAO. Thus, some varieties contain such high levels of cyanogenic glycosides that the cassava requires domestic processing in order to remove the toxins. Most of the cyanide can be eliminated by crushing or fermentation followed by heating. However, the detoxification product thiocyanate is a potent goitrogen. Moreover, the sugars in cassava may react with the ε-amino group of lysine in a Maillard reaction, making lysine unavailable (lysine is the second limiting amino acid in cassava protein).

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 20), and also by processing methods such as oven or sun drying. The HCN_p 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. 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 appear to be most effective to reduce the cyanide content. Calculating dry cassava as having 12% moisture, the estimated hydrocyanic acid potential of bitter cassava roots is approximately 110-1300 mg/kg dry weight, while levels are much lower in sweet varieties (50-100 mg/kg dry weight) (Ogunsua 1989; Chiwona-Karltun *et al*., 2004; Mkumbira *et al*., 2003).

Table 20. Hydrocyanic acid potential of fresh cassava leaves (at different maturity stages) and roots

Leaf		**Hydrocyanic acid potential/ HCN_p** (mg/kg dry weight)		
Stage of maturity	**Number from apex**	**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)

1. The HCN of 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 21). Many cassava products contain very low amounts of cyanogens, which can be efficiently eliminated by the body if the protein intake is adequate.

Table 21. Hydrocyanic acid potential and crude protein contents of cassava leaf meal as influenced by storage time

Storage time (months)	**HCN_p** (mg/kg DM [a])	**HCN loss as a percentage of initial level**	**Crude protein** (g/kg DM [a])
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

Source: Ravindran et al. (1987)
[a] Dry matter (DM)

C. Allergens

Cassava is not a commonly allergenic food. However, in recent years there have been several reports that described seven individuals who had suffered adverse allergy-like symptoms after oral ingestion or topical exposure to cassava (Caraballo *et al.,* 2001; Galvao *et al.,* 2004; Gaspar *et al.,* 2003, 2004; Ibero *et al*., 2004, 2007). 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.

The remainder of the subjects tested positive for latex-fruit allergy. 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. Cassava can thus be added to the list of fruits and vegetable to which latex allergy positive subjects could potentially cross-react.

SECTION IV-SUGGESTED CONSTITUENTS TO BE ANALYSED RELATED TO FOOD USE

A. Food uses and products

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 varieties can be classified as either the "sweet" (edible) variety or a "bitter" (poisonous) variety. Nutritionally, the cassava is comparable to potatoes, except that it has twice the fibre content and a higher level of potassium.

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, and to reduce cyanogenic potential of potentially toxic concentrations of cyanogenic glycosides to an 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 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.

Leaves of the cassava plant can be cooked in a manner similar to spinach. The young leaves, up to leaf position nine or ten, and the tender petioles and stem, 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 several countries in 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. There are country to country variations in the preference for particular varieties based on petiole colour, taste (bitter or sweet) and lower pest and pathogen susceptibility. Prior to cooking, cassava leaves are usually pounded or ground with pounding being the more popular method.

B. Suggested analysis for food use

The key nutrients and anti-nutrients suggested to be analysed in roots and leaves of new varieties of cassava intended for human consumption are shown in Table 22. If a cassava breeding objective was to produce higher levels of a particular mineral or vitamin not normally analysed (one of the aims of the Bio-fortification Program) (Sautter *et al*., 2007), then in this case these constituents should be included in root and leaf analysis.

Since appropriate key comparators may vary with age and maturity of cassava, it is recommended that data to be compared is obtained from plants of about 12 months of age, since much of the nutritional data available is on 12 month-old harvested cassava (harvested between 9-18 months; average 12 months).

Although cassava roots are considered to be a poor protein source in regions where food is abundant, it serves as an important source of protein in other countries, *e.g.* in Africa. Protein is evaluated in relationship to its biological value which is markedly influenced by the relative amounts of indispensable (essential) and dispensable (non-essential) amino acids and the form of nitrogen in the diet (WHO, 2007). WHO (2007) and NAS (2005) list the following nine amino acids as indispensible, *i.e.* those that have carbon skeletons that cannot be synthesized to meet body needs from simpler molecules: histidine, isoleucine, leucine, lysine, methionine, phenylanine, threonine, tryptophan and valine. Additionally, NAS (2005) identifies six amino acids as "conditionally indispensable", i.e. those requiring a dietary source when endogenous synthesis cannot meet metabolic needs: arginine, cysteine, glutamine, glysine, proline and tyrosine. However, WHO (2007) indicated that the requirement for indispensable amino acids is not an absolute value, and one must consider the total N content of the diet, including the dispensable amino acids particularly at lower levels of N consumption. Also potassium and calcium are important minerals to consider for both cassava tubers and leaves. Leaves are a fair source of iron. The vitamins beta-carotene and C as well as thiamine and riboflavin, are also important. Raw storage roots and leaves also contain phytic acid that binds phosphorus, making that portion of the dietary phosphorus unavailable to consumer.

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; 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 cyanogenic compounds are usually removed during cassava processing.

Table 22. Suggested constituents to be analysed in fresh roots and leaves of cassava

Constituent	Fresh leaves	Fresh roots
Proximate	X	X
Starch		X
Fatty acids	X	X
Amino acids	X	X
Minerals[a]	X	X
Vitamins[b]	X	X
Cyanogenic glycosides (linamarin and lotaustralin)	X	X
HCN	X	X
Tannins	X	
Phytic acid	X	

[a] Ca; P; Mg; Fe

[b] ß-carotene; Ascorbic acid (vitamin C); Thiamine; Riboflavin; Niacin

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

A. Livestock feed uses

Cassava roots, leaves and by-products have long been recognised as appropriate 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 during processing of cassava roots in Nigeria alone (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 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 (FAO Newsroom, 2008).

Cassava roots contain a very small amount of true protein (1.5 to 4.7/100 g DM), 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 in feed, 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). As powdered starch can produce ulcerogenic effects upon the gastric mucosa of some animals, 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, high in these components.

Cassava leaf preparations have a relative high protein content ranging from 18.9 to 27.3 g/100 g dry weight. Cassava leaf yields can be as much as 4.6 tonnes dry matter per hectare. In earlier times (reports from nutrition papers, 1970), most of the cassava forage material was returned to the soil as a ‘green manure’ product. However, there is an increased interest in using leaf products for animal feed (Ravindran, 1991). 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. There are also reports on less than optimal levels of tryptophan, isoleucine and threonine (Oguntimein, 1988). The comparatively high tannin content appears to cause lower amino acid utilization, probably because of tannins forming indigestible complexes with proteins.

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 degradation of proteins in cassava leaves to be 47%, in branches to be 28%, in the stems to be 56.9%, and in the whole crop to be 48.8%. Promkot and Wanapat (2003) reported 54.6% effective crude protein degradability for cassava hay. This is a relatively low degradation compared to other plant protein sources, suggested to be due to the relatively high content of condensed tannin in cassava foliage.

Ravindran (1991) reported that there is a good potential for using low levels of cassava leaf meal in diets for poultry and swine. Considering that the diet of animals should contain Ca and P in a ratio of 1.5-2 : 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 considered deficient in P. In the case of monogastric animals a proportion of the P would probably be bound in phytate and not be available to the animal, typical of most P in plants.

B. Suggested analysis for feed use

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 23.

Since appropriate key comparators may vary with age and maturity of cassava, it is recommended that data to be compared is obtained from plants of about 12 months of age, since much of the nutritional data available is on 12 month-old harvested cassava (harvested between 9-18 months; average 12 months).

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 glycosides (linamarin and lotaustralin), phytic acid, and tannins. Some constituents, such as fatty acids, either are found 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 intake 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 elements (one of the aims of the Biofortification Program) (Sautter *et al*., 2007).

While roots do not serve as a significant protein/amino acid source for animals, leaves -or products derived from leaves would. Although there are twenty primary amino acids that occur in proteins, there are only 10 or 11 that are recognized as essential, *i.e.* a need has been shown to be supplied by the diet (NAS, 2005). According to NAS (2005), the essential amino acids for swine include argenine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, tryptophan, valine and threonine. There is also a requirement for cystine and tyrosine, but these amino acids can be synthesized from methionine and phenylalanine, respectively. Content is also important, especially in swine and poultry diets. NAS (2005) lists the same amino acids as essential for poultry, plus glycine that is also included.

In cattle and sheep, where microbial protein from the rumen has been considered the primary protein source for the animal, there is increased interest in proteins that escape rumen fermentation, particularly in high producing dairy cattle. Thus, nutritionists are taking a closer look at the potential for cattle to also have certain limiting amino acids. Methionine, lysine, phenylalanine, and threonine have been suggested as being limiting amino acids for cattle.

Table 23. 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
Tannins	X	
Phytic acid	X	

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