Farmer Preference, Utilization, and Biochemical Composition of Improved Cassava (*Manihot esculenta* Crantz) Varieties in Southeastern Africa[1]

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Farmer Preference, Utilization, and Biochemical Composition of Improved Cassava (*Manihot esculenta* Crantz) Varieties in Southeastern Africa Cassava (*Manihot esculenta* Crantz) varieties are ethnobotanically classified by farmers into two distinct classes—"sweet" or "bitter"—based on their taste, most often reflecting the inherent cyanogenic glucoside potential and intended end use. Varietal preference based on general utilization as well as more targeted end use for preferred local and improved varieties is poorly understood and not well documented. The objectives of this study were to investigate prevailing varietal preferences based on utilization and the biochemical composition of local and recently improved cassava varieties. Interviews were conducted with farmers to document the existing varieties, their origin and taste classification, and processing in relation to end use. Biochemical composition was determined for flour samples with particular emphasis on color and perceived dryness. Of the nine varieties identified, four were classified as local, while the rest were classified as improved varieties. Two varieties were classified as bitter, and the rest were classified as sweet based on end use. The classification dichotomy based on taste is an important factor in determining potential toxicity. Labile varieties that are easily affected by microenvironmental factors were classified as bitter. Reasons for preference and utilization focus as much on the leaves for use as vegetables as on the roots. The taste classification of the roots determines how and whether they are to be processed. The varieties "Mweulu" and "Tanganyika" were perceived by farmers as having excellent characteristics for making the staple dish "nshima," reflected by their high carbohydrate contents. The variety "Bangweulu" was identified as having "bigger and starchier" roots in interviews, and the biochemical assay verified these observations. The flour sample analysis revealed crude protein content ranged from 4.86% to 7.09%. Cluster and principal component analyses showed four groupings, with the single Malawian variety exhibiting the greatest differences from the Zambian clones, while the improved varieties bred from a single mother line displayed the closest similarities. The high energy and carbohydrate values of the nine varieties provide a good basis for

[1] Received 25 April 2014; accepted 26 January 2015; published online ___________

Economic Botany, XX(X), 2015, pp. 1–15

Published online: 27 February 2015

acceptance; however, factors such as shelf life, storage, and other postharvest qualities such as susceptibility to weevil attacks also play a determining role in the acceptance of improved cassava varieties.

Makonda a Alimi, Kagwiritsidwe Ntchito, ndi kawuniwuni wa mitundu ya Chinangwa cha makono (*Manihot esculenta* Crantz) ku M'mwera Chaku M'mawa Kwa Africa Mitundu ya Chinangwa (*Manihot esculenta* Crantz) ilipo iwiri – "Chokoma" ndi "Chowawa" malingana ndi makomedwe ake. Mitundu iwiriyi imawunikiranso kusiyana kwa kagwiritsidwe ntchito ka mitundu imeneyi. Kagwiritsidwe nchito ka mitundu ya chinangwa yochokera mu kafukufuku kapena mitundu ina ya makolo sizimvetsetsedwa bwino komanso sizinalembedwe bwino. Zolinga za kafukufuku uyu zinali kufufuza makonda a kagwiritsidwe ntchito ka mitundu ya chinangwa ndi kawawidwe mu chinangwa cha makolo komanso cha makono. Alimi osiyanasiyana anafunsidwa pofuna kulembera mitundu yosiyana siyana imene ilipo, kumene inachokera ndi gulu lomwe chili malingana ndi kakomendwe kake, komanso kakonzedwe kake ndi ntchito yake. Kukoma kapena kuwawa kwa chinangwa kunatsimikizidwa poyesa ufa wake, polingalira mtundu ndi maumidwe ake. Mwa mitundu isanu ndi inayi imene inazindikiridwa, inayi inali ya makolo, pamene yotsalayo inali ya makono. Mwa mitundu isanu ndi inayi, iwiri inali yowawa, ndipo yotsalayo inali yokoma polingalira ntchito yomwe chimagwiritsidwa. Kusiyanitsa magawo polingalira kakomedwe, ndi chinthu chofunika kwambiri pofuna kudziwa kuopsya kumene kungakhalepo pa kudya chinangwa. Mitundu "yowawirako" imene imakhudzidwa kwambiri ndi kusinthasintha kwa nyengo inapezeka kuti ndi yowawa. Zifukwa zokondera chinangwa zimalingaliridwanso pa kakomedwe ka masamba ngati ntapasha ngati m'mene ziliri ndi mizu ya chinangwacho. Kusiyanitsa mitundu ya chinangwa mu kakomedwe kake kumapangitsanso kudziwa momwe chingakonzedwere. Alimi anawona mitundu ya "Mweulu" ndi "Tanganyika" kukhala ndi makhalidwe abwino opangira chakudya chomwe amachidalira "nsima" chifukwa ndi chokhutitsa ndiponso chopatsa mphamvu. Pochezanso ndi alimi, mtundu wa "Bangweulu" unapezeka kukhala ndi mizu yaikulu ndi ufa wambiri" ndipo kafukufuku anatsimikiziranso izi. Ufa wachinangwa unapezeka kukhala ndi puloteni wa mlingo wa pakati pa 4.86 – 7.09%. Kawuniwuni wa magulu a chingwachi anapeza magulu akulu-akulu anayi. Mtundu umodzi waku Malawi unaonetsa kusiyana kwakukulu ndi mtundu wofana nawo waku Zambia, pamene mtundu wamakono wopangidwa kuchokera ku kholo limodzi unawonetsa zinthu zofananiranako kwambiri. Kukhutitsa ndi kupereka mphamvu kwa mitundu isanu ndi inayi ya chinangwayi ndilo gwero lalikulu limene alimi amachikondera; komabe, zinthu monga nthawi yomwe chingatenge chisanaonengeke, kasungidwe, ndi masamalidwe chikakololedwa monga kugwidwa ndi anankafumbwe zimapangitsanso momwe mbewu ya makono ya chinangwa ingakondedwere.

Key Words: Bitter, cassava, cyanogenic glucoside, minerals, preference, starch, sweet utilization, varieties.

Introduction

Both farmers and scientists have established that cassava (*Manihot esculenta* Crantz) can be classified into two distinct classes—"sweet" or "bitter"—based on its inherent cyanogenic glucoside potential and use (Bradbury et al. 2013; Chiwona-Karltun et al. 1998; Dufour 1993; Mkumbira et al. 2003; Muhlen et al. 2000; Rogers 1963; Wilson and Dufour 2002). The sweet varieties usually contain much lower levels of cyanogenic glucosides than bitter ones (Carmody 1900; Chiwona-Karltun et al. 2004; Dufour 1994; Sundaresan et al. 1987). Several studies also have shown that age and environmental conditions may influence the concentration of these toxins in various parts of the cassava plant to some extent (Bokanga et al. 1994; Mahungu 1994). While sweet varieties can be eaten raw, boiled, or cooked without prior processing, bitter varieties are processed to reduce risk of residual cyanogens prior to consumption (Chiwona-Karltun et al. 2000; Dufour 1988; Ellen and Soselisa 2012; O'Brien et al. 1992). When farmers introduce cassava varieties into their cropping systems, these characteristics play an important role in the selection.

Recognition that cassava has moved beyond merely being a food–security crop in Sub–Saharan

Africa to becoming a commercial crop is increasing (Fermont et al. 2010; Nweke 2004; Nweke et al. 2001). Cassava is indeed gaining in importance after maize (Haggblade et al. 2012; Haggblade et al. 2003) and in climate change debates (Burns et al. 2010; Jarvis et al. 2012; Rosenthal and Donald 2012). However, there remain challenges, especially when it comes to varietal adoption (Alene et al. 2013). Varietal preference based on general utilization as well as more targeted end use for preferred local and improved varieties (Muoki and Maziya-Dixon 2013) is not well documented. Regarding small–scale farmers, a recent publication revealed that as little as 7% adoption of improved varieties tolerant to cassava mosaic diseases was observed in Malawi. This was because farmers did not perceive the varieties as having preferred consumption attributes. Similarly, farmers in Zambia preferred local varieties over improved varieties with adoption rates as low as 15% for improved varieties (Alene et al. 2013).

The objectives of this study were to investigate prevailing varietal preferences based on use and the biochemical composition of local and improved cassava varieties. Such information is important for understanding farmers' adoptions of new improved varieties. A series of interviews were conducted with farmers and researchers to document the existing varieties, their origin, classification, processing, and end use. Biochemical analyses were performed on the flour samples. The study was conducted in Zambia, one of three main cassava–producing and cassava–consuming countries in southeastern Africa (Malawi and Mozambique are the others). The varieties found in Zambia can be considered representative of the southeastern African countries.

Materials and Methods

Cassava Sample Collection

Five improved and four local cassava varieties were obtained from 15 farmers' fields in the Chisamba Community located in the Chongwe District in Zambia. The improved varieties were "Kampolombo," "Chila A," "Chila B," "Mweru," and "Tanganyika." Two recommended local varieties, "Nalumino" and "Bangweulu," are available through the Zambia Agricultural Research Institute (ZARI), while the two remaining local varieties, "Manyokola" and "Mweulu," spread mainly via farmer–to–farm distribution. Interviews with staff from ZARI indicated that improved varieties were observed to be more tolerant to cassava mosaic virus (CMV). These varieties were subsequently released to farmers by the cassava–breeding program at the Zambian Agricultural Research Institute (Alene et al. 2013).

Sampling and Preparation for Chemical Analysis

Root samples were harvested from the nine varieties and transported to the laboratory within three hours of harvest. The samples were cleaned, peeled, and washed with room–temperature water. Parts of the parenchyma from the distal, middle, and apical sections of peeled roots were cut into cubes and oven dried at 60°C for 48 hrs. The oven–dried cubes were ground in a Hammer mill (Christy and Norris Ltd., Model 2A, Chelmsford, Surrey, UK) into flour to pass through a 250–μm sieve. The flour samples obtained were then packaged into polypropylene bags and kept at room temperature (25°C) for analysis. Duplicate samples (~1 kg) of flour (approximately 8–10 cassava roots from several plants) were prepared for each variety, and triplicate analyses were conducted on each of the replicates. The mean values of all analyses were computed, and standard deviations were reported.

Analytical Methods

Proximate Analyses of Samples

Moisture, crude protein (N x 6.25), fat, and ash contents were determined using the Association of Official Analytical Chemists' (AOAC)–approved methods 925.10, 920.87, 920.85, and 923.03, respectively (AOAC 2005). Carbohydrate content was determined by calculating the difference. The energy content of the roots was determined by multiplying the percentages of crude protein, crude lipid, and carbohydrates by 16.7, 37.7, and 16.7, respectively (Siddhuraju et al. 1992). These conversion factors represent the Kcal per unit of protein, lipids, and carbohydrates.

Mineral Analyses

Phosphorus and calcium levels were evaluated by applying the AOAC–approved methods 948.09 and 944.03, respectively (AOAC 2005). Iron contents were also determined by the AOAC ortho–

phenanthroline method 944.02. Flame photometry was used for sodium and potassium, and atomic absorption spectrometry was used for the remainder of the minerals studied.

Statistical Analysis

Statistical analysis and graphical presentation were applied using Minitab (version 14) and Microsoft Office Excel (2007 version), respectively. Cluster analysis (cluster observation) was performed to group the different cassava varieties with similar characteristics. Principal component analysis (PCA) was used to ascertain patterns and explore relationships between the various parameters of the varieties.

Results and Discussion

Classification and Taste

Of the nine varieties identified by name by the farmers, four of the varieties were local while the remaining five were improved varieties. "Bangweulu" was the only variety clearly identified as bitter. During interviews, farmers further classified the improved variety "Chila" into two sub–classifications, henceforth referred to as "Chila A" and "Chila B." These varieties were classified as being slightly bitter. The other varieties—"Kampolombo," "Mweru," "Mweulu," "Tanganyika," "Nalumino," and "Manyokolo"—were classified as sweet. In the study area, there was a high proportion of the varieties originating from the national research stations, namely Kasama and Mansa, in Zambia (Table 1). During interviews, farmers indicated that the varieties "Mweulu" and "Tanganyika" were regarded as more disease– and drought–tolerant compared to the other varieties shown in Table 1.

Classifying cassava varieties on the basis of taste and end use is well established among cassava producers and consumers, extending its geographical origins of Brazil (Dufour 1994), the West Indies (Sauer 1963), Asia (Ellen and Soselisa 2012; Thaman and Thomas 1985), and Africa (Chiwona-Karltun et al. 1998). Taste is used as an important indicator and predictor of potential toxicity, especially of raw roots. Though studies show that there is a continuum of cyanogenic glucosides (Bokanga 1994) both at the varietal and the root levels, there are also studies showing a strong correlation between bitter taste and cyanogenic glucoside levels (Chiwona-Karltun et al. 2004). Sometimes other perceptual characteristics are used to classify varieties, but these do not carry the same specificity as the distinctive folk taxonomy of classifying varieties as bitter or sweet (Jones 1959; Nye 1991; Wilson and Dufour 2002). Studies in the neighboring country of Malawi verify the importance of the bitter and sweet taxonomy. When varieties are identified as being labile, that is, affected by microenvironmental factors to become more or less bitter, they were referred to as "intermediate varieties" (Chiwona–Karltun et al. 2004).

In this study, we found varieties classified by farmers as being "somewhat bitter," namely the varieties "Chila A" and "Chila B." To be conservative, farmers classify a variety as bitter when it has a tendency to be labile. This is supported by similar findings in Indonesia (Soselisa and Ellen 2013) and in a comparative study of cassava genetic differentiation between bitter and sweet cassavas (Bradbury et al. 2013). The necessity of using taste as a marker for potential toxicity is important, especially as evidence shows that the introduction of cassava to other areas outside its place of origin is often characterized by bitter varieties arriving first and the sweet ones arriving much later (Bradbury et al. 2013). Moreover, varieties whose levels of cyanogenic glucosides highly fluctuate as a result of the microenvironment potentially pose a threat, where knowledge and experience is predominantly based on folk taxonomy.

In a recent publication with data from Zambia, evidence showed little adoption by the farmers of the improved varieties. Much of the reason for this low usage included lack of awareness (Alene et al. 2013). Nevertheless, as seen in Table 1, results from our interviews show that tolerances to drought and diseases are factors that play a determining role in adoption. Although the improved varieties were perceived as performing well, the local varieties seemed to be preferred due to their resistance against pests and disease. These findings are also supported by earlier studies in Malawi, where farmers were found to keep a repertoire of local varieties (Mkumbira et al. 2003) even if they had access to new improved ones.

Preference and Utilization of Different Cassava Varieties

Reasons for preference and utilization focused as much on the cassava leaves for use as vegetables as

Table 1. SOURCES AND DESCRIPTION OF THE DIFFERENT CASSAVA VARIETIES AS DESCRIBED BY THE FARMERS.

	Part A: Source of cassava variety			Part B: Description of cassava variety		
Cassava variety	Source	Type and Taste Classification	Institution that introduced the variety	Characteristics of the leaves and stalks/stems	Characteristics of the tubers outer cover	Resistance to disease and drought tolerance
Kampolombo	Mansa Roots and Tubers Research Programme, Misamfu Research Station, Kasama	Improved sweet variety	Food Crop Diversification Support Project (FODIS)	Large brown leaves	Large light brown roots	Become less disease resistant after growing for a longer period (4Years). Less drought tolerant
Bangweulu	Same as above	Recommended local variety, bitter	FODIS	Purplish leaves	Brown roots	Less disease resistant and less drought tolerant
Chila	Same as above	Improved, slightly bitter variety	FODIS	Green leaves	Light brown roots	Disease tolerant but easily attacked by ants, a bit drought tolerant
Mweru	Same as above	Improved, sweet variety	FODIS	Brown stem	Medium brownish roots	Disease tolerant and not drought tolerant
Mweulu	Tanzania	Local, sweet variety	Chinsali District	Green thin leaves, reddish stalks	Brown outer cover but reddish roots	Disease resistant and drought tolerant
Tanganyika	Misamfu Research Station	Improved, sweet variety	FODIS	Light green leaves, whitish stalks	Whitish roots	Disease resistant and drought tolerant
Nalumino	Same as above	Recommended local variety, sweet	FODIS	Green leaves	Large brown roots	Disease resistant and attacked by ants during drought
Manyokola	Malawi, farmer–to–farm exchange and sharing	Local Malawian, variety, sweet	FODIS	Small green leaves	Medium whitish roots	Disease resistant, sheds leaves during drought

on the roots for making the staple dish "nshima" or for use as a complementary energy provider. As shown in Table 2, only the roots of the varieties classified as bitter ("Bangweulu" and "Chila") could not be readily eaten raw. However, roots of "Bangweulu" were found to be "bigger and starchier." Storage/shelf–life properties, especially after drying, were noted to be an important quality. The longer roots of varieties such as "Kampolombo" could be stored under local conditions that kept up to six months after processing; varieties with longer roots were valued and wanted.

Several studies have shown that cassava leaves play an important role in the diet in populations in Africa, Latin America, and some Asian countries (Coursey 1973; Katz et al. 2012; Lancaster and Brooks 1983; Yeoh and Chew 1976). While the potential for maximizing the use and consumption of these leaves has yet to be realized, our study showed it was important that varieties also produce good–quality leaves. Specifically, varieties like "Mweru," "Chila A," "Chila B," and "Mweulu" were prized for their leaves (Table 2). Ellen and Soselisa (2012) found that since the 1970s, communities growing cassava sometimes grew certain species such as *Manihot glaziovii* as an ornamental plant from which only the leaves could be harvested. In certain communities in Sub–Saharan Africa, it is not uncommon to find consumption of cassava leaves as high as 500g/person (Lancaster and Brooks

Table 2. PREFERENCE AND USE OF THE DIFFERENT CASSAVA VARIETIES.

Cassava Variety	Part C: Preference and use of the cassava varieties	
	Preference Reason(s) for liking the variety	How the variety is utilized
Kampolombo	The leaves are nice for relish, the roots can be cooked fresh because they are sweet and milled dried tuber makes a nice cassava mealy meal for *Nshima*.	The fresh roots can be eaten raw, cooked, or roasted. The fresh leaves are pounded and cooked as relish. The dried roots can be stored up to six months and milled into cassava mealy–meal and flour.
Bangweulu	The roots are bigger and more starchy and bitter	The dried roots can be milled into cassava mealy–meal and flour. The roots cannot be eaten raw but can be roasted after soaking.
Chila	High yield and is bitter	The dried roots can be milled into mealy–meal and flour. The roots cannot be eaten raw but can be cooked or roasted after soaking. The fresh leaves are pounded and cooked as relish.
Mweru	Roots are starchy and high yielding and sweet	The fresh roots can be eaten raw, cooked, or roasted. The fresh leaves are pounded and cooked as relish. The dried roots can be milled into mealy–meal and flour.
Mweulu	Gives high yields and it's not bitter	The fresh root can be eaten raw, cooked, or roasted. The fresh leaves are pounded and cooked as relish. The dried roots can be milled into mealy–meal and flour.
Tanganyika	Roots can be cooked fresh, are sweet	Can be eaten raw, cooked, or roasted. Milled into mealy meal and flour.
Nalumino	The roots grow bigger (after 2 years) and give a high yield and are sweet	The fresh root can be eaten raw, cooked, or roasted. The fresh leaves are pounded and cooked as relish. The dried roots can be milled into mealy–meal and flour.
Manyokola	The roots can be eaten anytime and have a very nice taste	The fresh root can be eaten raw, cooked, or roasted. The fresh leaves are pounded and cooked as relish. The dried roots can be eaten raw, cooked; roasted and dried chips can be milled into meal for flour.

1983). What seems to be less documented is whether there are specific breeding programs or varieties that are bred for cassava leaves as vegetables. Cassava leaves are reportedly high in protein (up to 23.1g/100g), micronutrients, and vitamins, and processing of the leaves has a marginal effect on the majority of the compositional nutrients (OECD 2009). During the dry season, which often coincides with the hungry season, cassava plants are sometimes the only source of vegetables to be eaten with the staple dish prepared from the flour derived from the roots of cassava (Chiwona-Karltun et al. 1998). Although general knowledge and documentation of the consumption of cassava leaves in Sub–Saharan Africa are available, there is need for establishing consumption patterns, consumption quantities, and varietal preferences. This information could enable breeders and food processors to be more targeted in their interventions.

The roots of cassava are perhaps the most valuable part of the plant, providing the cheapest source of calories and, in some cases, providing more than one–third of required daily calories (Falcon et al. 1984; Tonukari 2004). In our study, respondents described their varieties and attributes, specifically regarding starchiness, mealiness, flour properties, and cooking properties of the roots (Table 2). Respondents were very particular about how roots could be used based on being classified as bitter or sweet. Roots from sweet varieties can be eaten raw, boiled, or roasted and/or chipped, dried, or milled into flour because they contain low levels of cyanogenic glucosides (Mkumbira et al. 2003). Maintaining this dichotomy appears crucial, especially for determining usage. Our findings on varietal preference and use of the two bitter varieties "Bangweulu" and "Chila" also corroborate the view that bitter varieties produce bigger roots that are more starchy, even if this is a result of deliberate selection (Bradbury et al. 2013; Chiwona-Karltun 2001; Wilson and Dufour 2002). It is well documented that any form of processing of cassava roots greatly enhances shelf life, particularly if the moisture content is reduced to 12% on a dry–weight basis (OECD 2009).

Processing, Storage, and Shelf Life

If the variety were bitter (i.e., "Bangweulu" and both "Chila" varieties), soaking and fermentation comprised the primary method used to process cassava roots into flour (Table 3). The process included peeling the roots, washing them, soaking them for two to five days (depending on how much time is required for the roots to soften), and then drying. Roots from sweet varieties were chipped or grated and simply dried. In both instances, dried roots or chips could be directly milled into flour or stored in sacks without milling. For roots of bitter varieties, once soaking was complete, they could be mixed with roots from the sweet varieties to increase bulk. Roots from sweet varieties were sometimes soaked to acquire desired taste preferences. The flour processed from the two local varieties ("Mweulu" and "Tanganyika") were found to possess similar mealy and taste qualities as "nshima," which is prepared from maize flour. Storage characteristics included shelf life, post–processing, and hardiness to weevil attacks. One of the problems affecting postharvest storage of cassava is weevil infestations that greatly affect the color, appearance, and texture of the roots. The local varieties were identified as faring best in terms of long–term storage and against weevil infestation.

There is ample evidence suggesting that processing depends very much on preferred tastes, palates, and habits originating from consuming similar foods (Nweke et al. 2001). In this study, respondents indicated the local varieties were preferred because they produced a flour product that was very similar to maize meal. The method and preferred processing pathways were soaking and fermentation of roots, common in much African food preparation (Nweke 1995). Farmers further described the feeling of "cassava holding the stomach for a longer time," as shown in Table 3. For cassava to function as a preferred food, it must fulfill certain criteria, and this has been shown in several studies; e.g., certain bitter varieties preferred for the white appearance of the flour or the leaves tasting more tender or having a dark–green color (Chiwona-Karltun et al. 1998). Studies in Indonesia have also shown that classification was as important as grouping criteria, but cooking qualities and functionality of a variety were more highly regarded in rank (Soselisa and Ellen 2013). In terms of consumer studies exploring processed cassava products for marketing, these factors need to be considered, especially when transitioning from traditional to processed–food products (Jumah et al. 2008). In the absence of readily available markets and improved technologies for increasing shelf life, varieties that keep well in ground storage or postharvest lead to higher adoption rates, especially in marginalized areas (Haggblade et al. 2012).

Table 3. LOCAL PREFERRED PROCESSING METHODS AND STORAGE OF THE DIFFERENT CASSAVA VARIETIES.

Cassava variety	Part C: Processing methods and storage			
	Processing methods		Storage	
	Method(s) Used	Reason(s) for using this/these method(s)	Storage of flour and dried cassava products	Shelf life of flour and dried cassava products
Kampolombo	Chipping, grating, or soaking	Soaking method; people just like it.	Dried cassava products are stored in sacks.	Dried products can stay for a longer time without being attacked by weevils.
Bangweulu	Soaking. To increase bulk after soaking roots from Bangweulu, can be mixed with pounded chips of any sweet variety prior to drying.	To remove bitterness and danger and to acquire the desired fermented flavor	When milled, store for long as flour. The flour is stored in plastic packages when storing for shorter period.	Cassava flour, however, can store longer than dried products for 6–10 months.
Chila	Soaking method; for mealy meal. Chipping; for flour.			
Mweru	Chipping, grating, or soaking	Roots are soaked to acquire a fermented taste		
Mweulu	Chipping, soaking	Nshima produced from the chips is thick just like that of maize mealy meal. Nshima from the soaked cassava roots is slippery and holds in the stomach for a longer time.		
Tanganyika	Chipping. However, the chips can be soaked for a day (if they taste bitter) prior to drying	Nshima prepared from this cassava mealy–meal tastes like maize meal.		
Nalumino	Chipping, soaking	Has special taste when roots are soaked and fermented		
Manyokola		Harvested roots can stay up to two weeks if stored in a cool place and trimmed at the ends.		

Table 4. Proximate composition of the roots of different cassava varieties +/– std. dev. of 3 replicates.

Variety	*Moisture (%)	*Protein (%)	*Ash (%)	*Fat (%)	*Carbohydrate (%)	Energy (kJ100 g^{-1}DM)
Mweulu	10.07±2.09	4.92±0.84	1.76±0.04	0.88±0.01	82.38±1.19	1491.06±34.43
Mweru	11.91±1.68	4.86±0.98	1.72±0.05	0.79±0.01	80.55±2.70	1459.12±29.91
Chila A	10.20±2.18	4.86±0.24	1.85±0.01	0.86±0.01	81.79±1.93	1486.95±36.62
Chila B	10.33±1.45	4.99±0.00	2.34±0.03	0.81±0.02	81.54±1.46	1475.48±25.08
Bangweulu	8.46±1.19	5.66±1.20	1.95±0.01	0.81±0.01	83.53±1.08	1513.12±19.75
Manyokola	11.52±2.17	5.26±0.36	1.90±0.02	0.87±0.01	80.86±1.84	1464.13±36.51
Kampolombo	11.04±0.93	7.09±1.71	1.78±0.08	0.80±0.05	79.29±0.65	1472.62±16.00
Tanganyika	11.23±1.80	5.04±1.60	1.90±0.01	0.73±0.03	80.48±0.24	1466.15±29.68
Nalumino	11.03±0.81	4.91±0.48	1.97±0.02	0.86±0.03	81.22±1.27	1470.95±14.49

*Values reported on dry weight basis

Proximate Composition of the Different Cassava Varieties

Table 4 shows the proximate composition of the roots of the nine different cassava varieties studied. The moisture content of the flours varied from 8.46% to 11.91%. Moisture is an important parameter in the storage of cassava flour; levels greater than 12% allow for microbial growth, while low levels are favorable and give relatively longer shelf life (Afoakwa et al. 2011; Trèche and Massamba 1991). Padonou et al. (2005) reported water content for cassava between the range of 60.3% to 87.1% on a fresh–weight basis, while others found moisture for different cassava flour samples to vary from 9.2% to 12.3% (Charles et al. 2005) and 11% to 16.5% (Shittu et al. 2007). Hence, the flour samples analyzed in our study are representative for such samples in general, and this agrees with the Organization for Economic Cooperation and Development (OECD) consensus report (OECD 2009).

Cassava roots are reported to have low protein content. The OECD consensus report describes the interval of mean values from six studies to range from 1.5 g/100g to 4.7 g/100g dry matter (OECD 2009). The crude protein content of the nine varieties investigated here ranged from 4.86% to 7.09%. The protein content of several of the varieties was therefore higher than the previously reported protein contents for cassava. This may be attributed to varietal differences and/or soil–quality characteristics within the southeastern African region.

Ash is a reflection of the inorganic mineral elements present in the samples, and cassava is reported to contain 1% to 2.84% dry weight ash content (Aryee et al. 2006). The ash contents of the cassava flour samples in this study ranged from 1.72% to 2.34%, with "Mweru" having the lowest and "Chila B" the highest. Similar findings (1.72% to 2.34%) were reported by Afoakwa et al. (2011) in six cassava varieties commonly grown in Ghana.

Fats are vital to the structure and biological functions of cells (Eleazu and Eleazu 2012). Cassava contains low amounts of fats. Charles et al. (2005) found the fat content of cassava varieties to range from 0.1% to 0.4%, while Padonou et al. (2005) found cassava to contain 0.65% fat. All the cassava varieties investigated here had comparatively higher fat contents with values ranging from 0.73% ("Tanganyika") to 0.88% ("Mweulu"). Similarly, relatively high fat contents (0.74% to 1.49%) were also reported by Afoakwa et al. (2011) in six cassava varieties commonly grown in Ghana.

Cassava roots are rich sources of carbohydrates. Cassava carbohydrate content ranges from 32% to 35% on a fresh–weight basis and 80% to 90% on a dry–weight basis (Montagnac et al. 2009). With the exception of the "Kampolombo" variety, which recorded the least carbohydrate value of 79.29%, all cassava varieties recorded high carbohydrate contents, which were within the 80% to 90% range reported by Montagnac et al. (2009). The statement by farmers that "Bangweulu" roots are "bigger and starchier" (Table 2) agrees with the variety showing the highest carbohydrate percentage (Table 4). Energy contents ranged from 1,459.12 kJ/100 g dry matter for "Mweru" to 1,513.12 kJ/100 g dry matter for "Bangweulu."

Mineral Content of the Different Cassava Varieties

The physiological role of minerals in the human diet has been widely reported (Prasad et al. 1978). Minerals are needed for growth and maintenance of body structures. The human body uses minerals for the proper composition of bone and blood as well as the maintenance of normal cell function. Thus, diets rich in minerals are essential for proper growth and development (Golden 2002). Cassava is, however, reported to contain low levels of minerals compared to cereals, but contents of most elements are comparable to Irish potatoes (OECD 2009). The mineral content of the cassava varieties in this study are shown in Table 5. The most abundant mineral in all the cassava varieties studied was potassium followed by sodium, phosphorus, iron, calcium, and magnesium. Manganese was the mineral with the least concentration, while zinc had appreciable values. Potassium content ranged from 681 mg/100g to 1,220 mg/100g; it was highest in "Chila B" and lowest in "Manyokola." Results obtained in these varieties were generally lower than the reported 324–554 mg/g (32,400–55,400 mg/100g) (Charles et al. 2005) but higher than the values (0.25–0.36 mg/100g) reported by Afoakwa et al. (2011). Sodium ranged from 172 mg/100g ("Nalumino") to 459 mg/100g ("Bangweulu"). Phosphorus, iron, and calcium contents were 62,212, 95,200, and 26,120 mg/100g, respectively. Manganese was found in the least amounts in all cassava varieties, with values ranging from 2.88 mg/100g ("Mweru") to 3.64 mg/100g ("Chila B"). These were, however, higher than values reported by Afoakwa et al. (2011) (0.021–0.03 mg/100g) and higher than the greatest value (0.95) and within the range of means reported by the OECD from three other studies (2009).

Cluster and Principal Component Analyses for Chemical Composition of Cassava Varieties

Cluster and principal component analyses were applied to the chemical composition of the different cassava samples in order to explore patterns and relationships among the varieties based on their chemical composition. Results from the principal component analysis applied to the chemical composition of the cassava varieties showed that two components explained a total of 58.9% of the total variability in the data. The first principal component (PC1) accounted for 33.8% of the total variation in the nutritional characteristics, while the second (PC2) explained 25.1% (Fig. 1). The clustering of the plots reveals several important distinctions among the varieties. Not surprisingly, the Malawian variety "Manyokola" differs quite

Table 5. Mineral (mg/100g) composition of the roots of different cassava varieties +/– std. dev. of 3 replicates.

Variety	K	Na	Ca	Mg	P	Fe	Mn	Z
Mweulu	974.41±0.12	379.13±1.33	83.27±0.02	88.09±0.05	211.62±1.00	150.49±0.08	3.28±0.10	9.65±0.01
Mweru	1150.79±0.11	444.05±1.25	105.36±0.09	82.84±0.02	130.71±1.01	95.44±0.02	2.88±0.00	8.33±0.01
Chila A	996.09±0.01	307.81±1.33	89.16±0.03	75.78±0.01	111.09±1.33	108.50±0.01	3.32±0.00	10.74±0.01
Chila B	1219.27±0.03	301.48±1.12	94.49±0.06	99.04±0.03	136.92±1.11	109.05±0.02	3.64±0.01	8.95±0.01
Bangweulu	1192.12±0.02	458.62±1.02	71.43±0.04	85.32±0.03	97.79±1.10	100.49±0.00	3.05±0.01	9.75±0.01
Manyokola	680.93±0.10	240.45±0.89	26.26±0.04	45.82±0.00	83.42±1.42	200.78±0.04	3.11±0.00	11.48±0.01
Kampolombo	1146.25±0.00	379.45±0.97	120.45±0.05	93.28±0.01	133.90±0.98	97.33±0.01	3.06±0.00	11.46±0.01
Tangayoka	1024.88±0.05	446.27±0.58	117.91±0.02	77.51±0.01	107.72±1.52	101.59±0.00	3.09±0.00	9.65±0.01
Nalumino	872.94±0.04	171.58±1.00	45.78±0.06	75.07±0.02	62.32±1.53	102.82±0.04	3.30±0.01	8.24±0.02

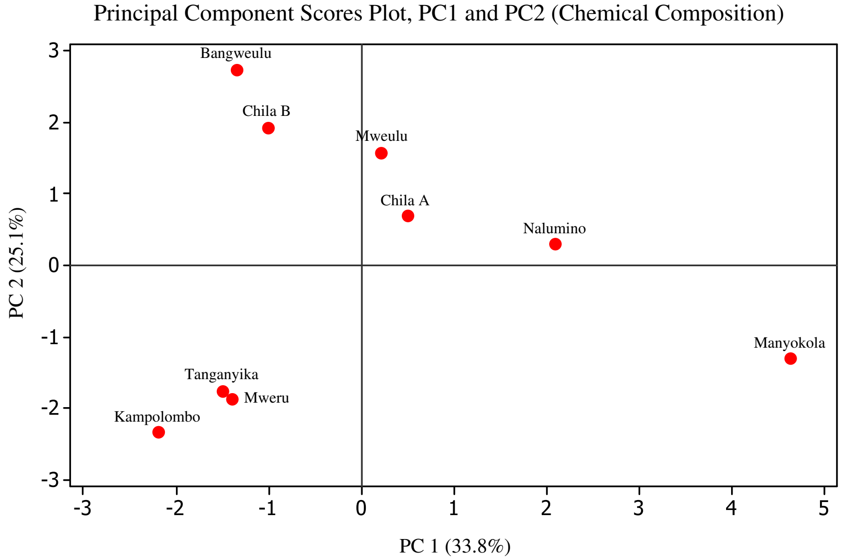

Fig. 1. Sample scores of plot for the principal component analysis of chemical composition of cassava varieties.

substantially from the Zambian clones. These differences explain its isolation in the southeast quadrant of Fig. 1.

In contrast, the tight cluster in the southwest quadrant includes three of the four improved varieties bred and released by ZARI. The recommended local variety "Nalumino" served as the mother line for breeding all four of the improved varieties evaluated here (Alene et al. 2013). This common ancestry likely explains the many common chemical characteristics shared by "Kampolombo," "Tanganyika," and "Mweru." The remaining progeny, "Chila," is clearly more labile than the other varieties, according to both the farmer assessments and the chemical analysis. This property makes it more susceptible to influences from its microenvironment. As a result, "Chila A" and "Chila B" display distinctly different chemical properties, despite identical genetic makeup. If inherited, in part, from its mother line "Nalimino," this property could

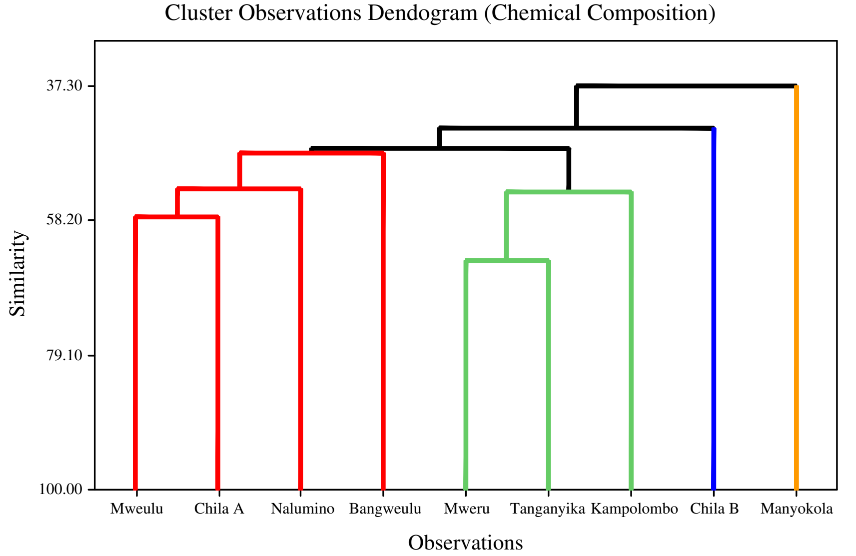

Fig. 2. Cluster observations dendrogram for chemical composition of cassava varieties.

explain the distance observed between "Nalumino" and her four progeny. Bangweulu, the other recommended local variety, retains distinct properties that place it in the far northwest corner of the plot.

The cluster dendrogram showed that the nine cassava varieties grouped into four clusters based on chemical composition (Fig. 2). This clustering closely follows the patterns observed in Fig. 1. "Manyokola," the Malawian variety, lies clearly distinct in its own cluster. Similarly, the three non–labile improved varieties—"Mweru," "Tanganyika," and "Kampolombo"—are grouped together in one cluster. The highly labile "Chila" is grouped in two separate clusters, "Chila–A" in red and "Chila–B."

Conclusion

Preference for specific cassava varieties, whether local or improved, is heavily determined by end–use and inherent cyanogenic glucoside content. The taste of raw roots, classified as sweet or bitter based on whether processing is required prior to consumption, is a commonly used classification. Varieties that have high carbohydrate and starch contents are deemed important when making preferred staple dishes. An equally important quality concerns cassava leaves when they contribute significantly as vegetables; varieties producing leaves with high palatability are prized. There are few, if any at all, studies that have systematically looked at cassava varieties in relation to preference for cassava leaves. Cassava leaves as vegetables and their consumption patterns are not well understood and require further study. Within the cassava roots studied here, all varieties had appreciable levels of nutrients. The most abundant mineral in all the cassava varieties studied was potassium, followed by sodium, phosphorus, iron, calcium, and magnesium. Manganese was the mineral with the least concentration, while zinc had appreciable values. Carbohydrate and energy densities of all the varieties were high, suggesting that these cassava varieties could be used as a reliable food and energy source. The cluster dendrogram showed that the nine cassava varieties grouped into four clusters based on their chemical composition. The strong similarity among the three non–labile improved varieties ("Mweru," "Kampolombo," and "Tanganyika") implies that these improved varieties would stand a higher chance of acceptance than the highly labile improved variety "Chila." The high susceptibility of "Chila" to local soil and environmental influences will likely make its uptake more difficult. More importantly, this malleability highlights once again the importance of understanding local farmer practices for tasting and assessing the chemical characteristics of the cassava varieties they grow.

Acknowledgments

The authors wish to thank the following donors for financing the fieldwork and analytical studies that made this paper possible: the Swedish International Development Agency (Sida) through its Cassava Transformation in Southern Africa (CATISA) project and the Swedish Ministry of Foreign Affairs Food Security Initiative special support to the Swedish University of Agricultural Sciences (UD40). They, likewise, wish to acknowledge valuable feedback received from Martin Chiona and the two anonymous reviewers. Further, the authors are grateful to the local language translator for providing translation of the abstract from English to Chinyanja and Joseph Nagoli. Any mistakes of fact or interpretation, nonetheless, remain the sole responsibility of the authors.

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