1

Introduction to Tropical Roots and Tubers

Harish K. Sharma and Pragati Kaushal

Department of Food Engineering and Technology, Sant Longowal Institute of Engineering and Technology, Sangrur, India

1.1 Introduction

Roots and tubers are considered as the most important food crops after cereals. About 200 million farmers in developing countries use roots and tubers for food security and income (Castillo, 2011). The roots and tubers contribute significantly to sustainable development, income generation and food security, especially in the tropical regions. The origin of tropical roots and tubers along with their edible parts is presented in Table 1.1.

Individually, cassava, potato, sweet potato and yam are considered the most important roots and tubers world-wide in terms of annual production. Cassava, sweet potato and potato are among the top ten food crops, being produced in developing countries. Therefore, tropical roots and tubers play a critical role in the global food system, particularly in the developing world (Amankwaah, 2012). The leaders, policy-makers and technocrats have yet to completely recognize the importance of tropical tubers and other traditional crops. Therefore, there is a need to focus more on tropical roots and tubers to place them equally in the line of other cash crops.

Tropical root and tubers are the most important source of carbohydrates and are considered staple foods in different parts of the tropical areas of the world. The carbohydrates are mainly starches, concentrated in the roots, tubers, corms and rhizomes. The main tropical roots and tubers consumed in different parts of the world are taro (*Colocasia esculenta*), yam (*Dioscorea* spp.), potato (*Solanum tuberosum* L.), sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*) and elephant foot yam (*Amorphophallus paeoniifolius*). Yams are of Asian or African origin, taro is from the Indo Malayan region, probably originating in eastern India and Bangladesh, while sweet potato and cassava are of American origin (Table 1.1). Naturally suited to tropical agro-climatic conditions, they grow in abundance with little or no artificial input. Indeed, these plants are so proficient in supplying essential calories that they

---

Tropical Roots and Tubers: Production, Processing and Technology, First Edition.
Edited by Harish K. Sharma, Nicolas Y. Njintang, Rekha S. Singhal and Pragati Kaushal.

Table 1.1 Origin of tropical roots and tubers

Tropical roots and tubers	Origin	Edible part
Sweet potato	Central/South America	Root, leaves
Cassava	Tropical America	Root, leaves
Taro	Indo-Malayan	Corm, cormels, leaves and petioles
Yam	West Africa/Asia	Tuber
Elephant foot yam	Southeast Asia	Tuber

Figure 1.1 Post-harvest handling stages in the storage of tropical roots and tubers.

are considered a “subsistence crop” (www.fao.org). Because of their flexibility in cultivation under a mixed farming system, tropical roots and tubers can contribute to diversification, creation of new openings in food-chain supply and to meet global food security needs.

The perishability and post-harvest losses of tropical roots and tubers are the major constraints in their utilization and availability. The various simple, low-cost traditional methods are followed by farmers in different parts of the world to store different tropical roots and tubers. The requirements of storage at different stages during the post-harvest handling of tropical roots and tubers are presented in Figure 1.1. The perishable nature of roots and tubers demands appropriate storage conditions at different stages, starting with the farmers to their final utilization (consumers). Therefore, an urgent requirement exists to modernize the traditional methods of storage at different levels, depending upon the requirements of keeping quality.

The various interactive steps involved in post-harvest management of any tropical root or tuber, if not controlled properly, may result in losses. To prevent these losses, several modern techniques such as cold storage, freezing, chemical treatments and irradiation may be widely adopted. Roots and tubers not only enrich the diet of the people but are also considered to possess medicinal properties to cure various ailments. So the role of roots and tubers in functional products can also be investigated in the light of medicinal properties. An immense scope exists for commercial exploitation in food, feed and industrial sectors. Since tropical roots and tubers crops are vegetatively propagated and certification is not common, the occurrence of systemic diseases is another problematic area. Some of these root and tuber crops remain under-exploited and deserve considerably more research input for their commercialization.

1.2 Roots and Tubers

1.2.1 Roots

The root is the part of a plant body that bears no leaves and therefore lacks nodes. It typically lies below the surface of the soil. Edible roots mainly include cassava, beet, carrot, turnip, radish and horseradish. Roots have low protein and dry matter compared to tubers. Moreover, the major portion of dry matter contains sugars. The major functions of roots include absorption of inorganic nutrients and water, anchoring the plant body to the ground and storage of food and nutrients.

1.2.2 Tubers

Tubers are underground stems that are capable of generating new plants and thereby storing energy for their parent plant. If the parent plant dies, then new plants are created by the underground tubers. Examples of tubers include potatoes, water chestnuts, yam, elephant foot yam and taro. Tubers contain starch as their main storage reserve and contain higher dry matter and lower fiber content compared to roots. Various tropical roots and tubers are presented in Figure 1.2.

The production of roots and tubers can be grouped into annuals, biennials and perennials. The perennial plants under natural conditions live for several months to many growing seasons, as compared to annual or biennial. The main points of difference among annuals, perennials and biennials are presented in Table 1.2. The perennials generally contain a greater amount of starch as compared to biennials.

1.3 Requirements for the Higher Productivity of Tropical Roots and Tubers

The factors that need to be focused upon to meet the objectives of food security, sustainable farming and livelihood development are farming systems, pest and pathogen control systems, genetic systems and strategies for improvement, together with marketing strategies and the properties of the products and constituents.

1.3.1 Farming Systems

Tropical roots and tubers are generally grown in humid and sub-humid tropics, which are not suited for cereal production. Significant differences exist in the farming system perspectives of tropical root and tuber crops, varying from complex systems of

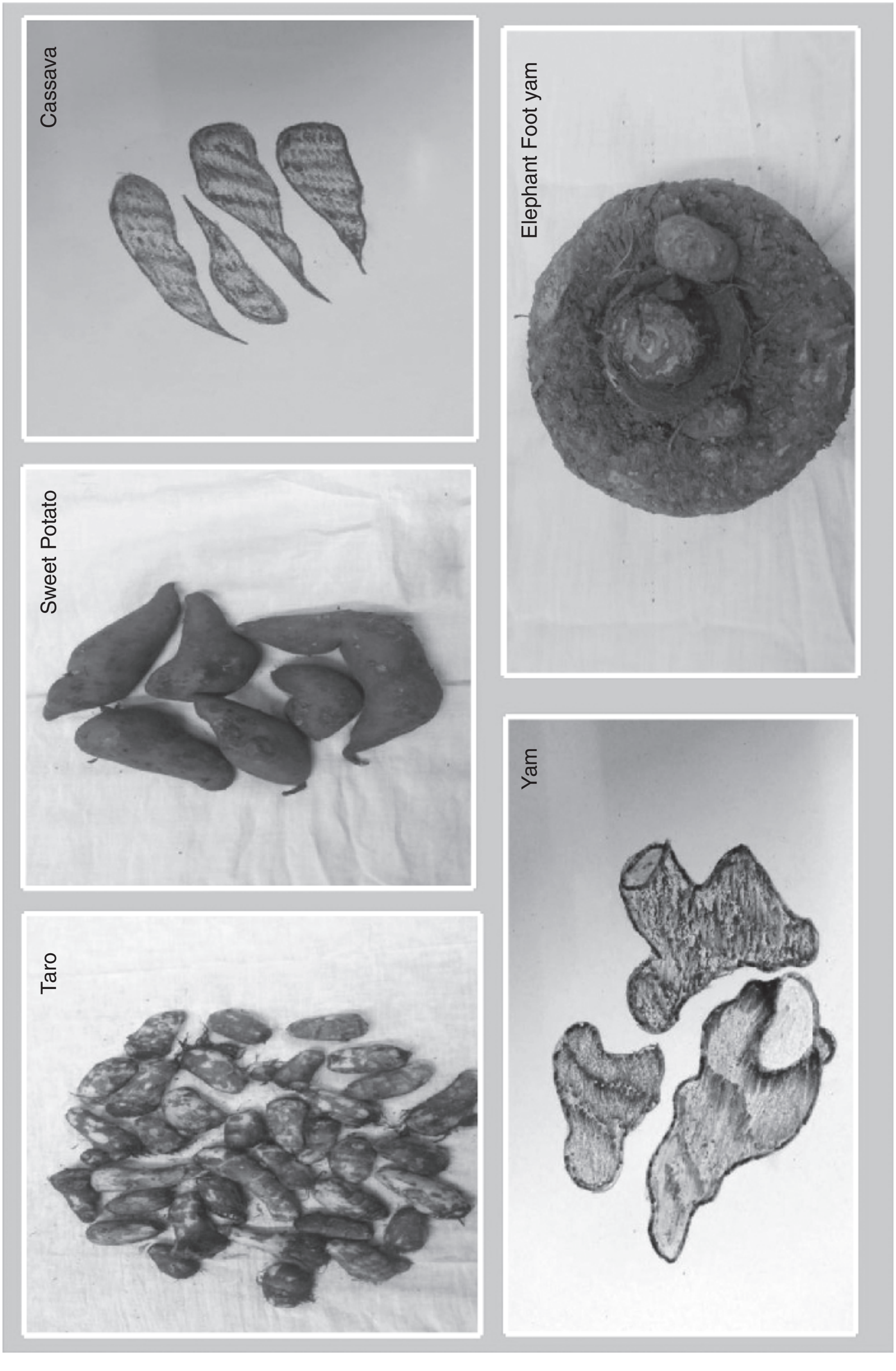

Figure 1.2 Various tropical roots and tubers.

Table 1.2 Annual, biennial and perennial roots/tubers

	Life cycle	Limiting aspects	Benefits
Annual	Takes 1 year to complete its life cycle.	Growth can be a limiting factor in excess/ scarcity of water for annual plants. Insect and disease problems are of minor concern.	Lesser benefits as compared to perennials and biennials.
Biennial	Takes 2 years to complete its life cycle.	Early growth and quality is affected by late-season moisture stress.	Provides lesser benefit as compared to perennials in agriculture.
Perennial	Takes more than 2 years to complete its life cycle.	No specific period for growth. But by providing early and modified irrigation practices, production can be improved.	They can hold soil to prevent erosion, do not require annual cultivation, reduce the need for pesticides and herbicides, and capture dissolved nitrogen.

production to intercropping farming systems. These systems are important to consider when studying the variation of different crop farming systems. The increasing production in the Pacific region has depended largely on farming more land rather than increasing crop yields. This is contrary to the projections of FAO that the 70% growth in global agricultural production required to feed an additional 2.3 billion people by 2050 must be achieved by increasing the yields and cropping intensity on existing farmlands, rather than by increasing the amount of land brought under agricultural production (Hertel, 2010).

Farming systems need to be carefully looked after, by protecting and raising the production of tropical roots and tubers. For this purpose, various changes in attitudes and agricultural practices are desirable. Additional investments are required to reduce the impact of climate change and to overcome the disastrous effects of soil erosion. Diversity in the production of tropical roots and tubers and increasing production surface area may be adopted for higher productivity and better quality of tropical roots and tubers. Proper organization among small farmers, effective investment in mechanization, and improved storage and processing facilities can improve the productivity of tropical roots and tubers.

1.3.2 Pest and Pathogen Systems

The pest and pathogens of different tropical roots and tuber crops are varied. Roots and tubers are generally produced by small-scale farmers, debarring a few exceptions using traditional tools and without the adequate input of fertilizers or chemicals for pest and weed control. Therefore, the correct use of less expensive and effective dosages of pesticides and fertilizers is important to increase the productivity of these crops. Moreover, the activities need to be designed to reduce environmental degradation. Biochemical approaches need to be followed to reduce the damage due to pests and pathogens. The assessment of loss caused by pests and pathogens cannot be overlooked, which otherwise affects the production of tropical roots and tubers. In addition, pest and pathogens are of particular concern because of their direct effect on human and animal health. The effect of climatic conditions on the damaging action of pests and pathogens needs to be highlighted. Therefore, proper crop protection, involving different management practices, needs to be followed to reduce the damage due to pests and pathogens and to enhance the productivity of tropical roots and tubers.

1.3.3 Genetic Systems and Strategies for Genetic Improvement

The genetic system of roots and tubers widely differs, so the strategies for genetic improvements also differ. The breeding of root and tuber crops is primarily done sexually. The fact is that the different genetic systems suffer from many breeding complications along with limited opportunities for genetic development and further modifications (Mackenzie, 1995).

Some of the tubers, such as sweet potato and potato, may benefit from breeding cultivars, which are adapted to shorter growing seasons, while other crops (e.g. cassava) may need to fit into some other system, as they have contrasting growing cycles (Mackenzie, 1995). Hundreds of genetically distinct varieties of the roots and tubers are known to exist. Therefore, a focus is needed to genetically improve and develop the variety of roots and tubers, depending upon the requirement to achieve the required target. The dissemination of knowledge to the field is also a great concern in the area. Other considerations (e.g. crop management practices and crop diversification) specify that the decision-making should be carried out in individual breeding programs so as to benefit from these advancements. The needs for improvement in the programs are actually unique for a specific crop, rather than to the group of these crops classified as tropical roots and tubers.

Higher production can be achieved by exploring the genetic yield potential and by gaining knowledge about the genetic background of tropical roots and tubers (Okoth *et al.,* 2013). Proper plant breeding approaches and genetic modification need to be followed for creating new genetic varieties. Overall, modern breeding technologies open up new possibilities to create genetic variation and to improve selection, but conventional breeding techniques remain important to improve the production of these crops.

1.3.4 Marketing Strategy

Tropical roots and tubers produced for off-farm markets can vary considerably in their transportation, storage facilities, processing techniques, consumption patterns, economics, etc. These differences need to be taken into account when various opportunities are assessed for improving trade. In fact, some individual root and tuber crops are presently experiencing a segmentation of markets that will undoubtedly require substantially different types of cultivars to meet divergent market needs (www.fao.org).

The true potential of tropical roots and tubers may be unlocked through various value-adding activities. Their processing level needs to be divided into two levels, the primary level and the secondary level. Therefore, various facilities need to be provided at each level to enhance their potential. Processing of tropical roots and tubers into different products will enhance options to the consumers. This diversity may create a large market space within which food processors can make long-term development plans supported by various growth prospects for investments in the processing of tropical roots and tubers.

1.3.5 The Properties of the Product and Constituents

The selection of raw material and products is mainly dependent on the physico-chemical, microbiological and sensory properties of the product itself and its constituents. For example, in the case of snacks (chips), the level of carbohydrate (reducing sugars) is regulated in the product, therefore monitoring the level of this parameter becomes very important for industry along with the other physico-chemical and sensory parameters of that product. Recently, there has been a great deal of research into the area of characterization of tropical roots and tubers. However, the methods required to evaluate the quality characteristics and the product potential are to be identified for different roots and tubers. The relevant characteristics of tropical roots and tubers based upon their optical, physicochemical and mechanical properties need to be recorded in the field to ascertain their quality. In addition, the required processing technologies and the properties of the products thereof need also to be established and disseminated globally for roots and tubers. This information gap represents a whole new area of research that needs to be addressed if post-harvest technology of tropical root and tuber crops is to become a reality.

1.4 World Production and Consumption

Roots and tubers can be grown under diverse environmental conditions and in different forms of farming systems. The choice of food by rural consumers is generally determined by the agricultural production in their area, whereas the choice of urban consumers, who have developed a preference for more convenience foods, is partly determined by the availability and convenience of low-cost imports and most significantly by their improved purchasing power (Aidoo, 2009).

In South America and the Caribbean, overall per capita consumption of roots and tubers has declined by 2.5% per annum since 1970, while a growth of 1% is recorded in consumption of cereals (FAO, 1987). This reflects the lower preference of urban populations in towns and cities towards the consumption of roots and tubers. The major tropical roots and tubers are cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas* L.), yam (*Dioscorea* spp.), edible aroids (*Colocasia esculenta* and *Xanthosoma sagittifolium*) and elephant foot yam (*Amorphophallus paeoniifolius*). These are widely cultivated and consumed in many parts of Latin America, Africa, the Pacific Islands and Asia.

It is estimated that more than 600 million people depend on cassava in Africa, Asia and Latin America (www.fao.org). Global output is forecast to reach new records in the near future, driven by population expansion in Africa and Asia. World cassava output in 2013 showed the expected marginal increase from 2012 and is expected to continue to show an approximate 7% annual rise in succession. The expansion is possibly being fuelled by the rising demand for food and increasing industrial applications of cassava, especially for producing ethanol and starch.

Cassava remains a strategic crop in Africa, for both food security and poverty alleviation (Howeler, 2008). The world cassava areas, yield and production from 1995–2011 is presented in Table 1.3. Cassava production increased from 162.48 million tons in 1995 to 252.20 million tons in 2011, whereas an increase in area from 16.46 million ha in 1995 to 19.64 million ha in 2011 has been observed. The world average cassava yield, 9.87 ton/ha in 1995 increased to 12.84 ton/ha in 2011 (Table 1.3).

The world leading producers for different tropical roots and tubers in 2012 are given in Table 1.4. Nigeria is the top producer for cassava, yam and taro, whereas China is the top producer for sweet potato (Table 1.4).

Sweet potato is considered a solution for the emergent challenges being faced by the developing world, such as climate change, disease, migration and civil disorder (Beddington, 2009). Yams are ranked as the fourth major crop in the world after cassava, potatoes and sweet potatoes (Adeleke and Odedeji, 2010). Yams are recognized by their high moisture content, which makes them more susceptible to microbial attack and brings out their high perishability, with an annual production of more than 28 million metric tonnes (FOS, 2011). Production of yams in Africa is largely concentrated in the area popularly known as the "yam zone", comprised of areas such as Cameroon, Nigeria, Benin, Togo, Ghana and Côte d'Ivoire, where approximately 90% of the world's production takes place (Hamon *et al.*, 2001). Ghana is the leading exporter of yam, accounting for over 94% of total yam exports in West Africa. Total yam production in Ghana has increased from 877 000 to 5 960 490 tonnes from 1990 to 2010, mainly due to efforts by smallholder farmers. However, the highest yam production in 2012 was reported in Nigeria (38 000 000 MT), followed by Ghana (6 638 867 MT) (Table 1.4).

Taro is currently grown in nearly every tropical region of the world. Taro has been a staple crop for the inhabitants of the Pacific Islands for many years and is considered an integral part of the farming systems and diet of many people living in the Pacific Islands. Nigeria stands on top, with a production of 3 450 000 MT for taro in the year 2012 (Table 1.4).

Table 1.3 World cassava areas, yield and production from 1995–2011

Year	Areas (million ha)	Yield (ton/ha)	Production (million tons)
1995	16.46	9.87	162.48
2000	17.00	10.38	176.53
2005	18.42	11.18	205.89
2006	18.56	12.06	223.85
2007	18.42	12.28	226.30
2008	18.39	12.62	232.14
2009	18.76	12.51	234.55
2010	18.46	12.43	229.54
2011	19.64	12.84	252.20

Source: FAO (2013)

Table 1.4 World leading tropical roots and tubers producers in 2012

	Cassava		Sweet potato		Yam		Taro	
S. no	**Country**	**Production (MT)**	**Country**	**Production (MT)**	**Country**	**Production (MT)**	**Country**	**Production (MT)**
1	Nigeria	54 000 000	China, mainland	77 375 000	Nigeria	38 000 000	Nigeria	3 450 000
2	Indonesia	24 177 372	Nigeria	3 400 000	Ghana	6 638 867	China, mainland	1 760 000
3	Thailand	29 848 000	Uganda	2 645 700	Côte d'Ivoire	5 674 696	Ghana	1 270 266
4	Democratic Republic of the Congo	16 000 000	Indonesia	2 483 467	Benin	2 739 088	Cameroon	1 614 103
5	Ghana	14 547 279	United Republic of Tanzania	3 018 175	Togo	864 408	Papua New Guinea	250 000
6	Brazil	23 044 557	Vietnam	1 422 501	Cameroon	537 802	Madagascar	232 000
7	Angola	10 636 400	Ethiopia	1 185 050	Central African Republic	460 000	Japan	172 500
8	Mozambique	10 051 364	United States of America	1 201 203	Chad	420 000	Rwanda	130 505
9	Vietnam	9745545	India	1 072 800	Papua New Guinea	345 000	Central African Republic	125 000
10	India	8746500	Rwanda	1 005 305	Colombia	344 819	Egypt	118 759
11	Cambodia	7613697	Mozambique	900 000	Haiti	298 437	Philippines	111 482
12	United Republic of Tanzania	5462454	Kenya	859 549	Ethiopia	1 117 733	Burundi	92 973
13	Uganda	4 924 560	Japan	875 900	Cuba	366 182	Thailand	90 000

(*continued overleaf*)

Table 1.4 (*continued*)

	Cassava		Sweet potato		Yam		Taro	
S. no	**Country**	**Production (MT)**	**Country**	**Production (MT)**	**Country**	**Production (MT)**	**Country**	**Production (MT)**
14	Malawi	4 692 202	Burundi	659 593	Japan	166 100	Democratic Republic of the Congo	70 000
15	China, mainland	4 560 000	Angola	644 854	Brazil	246 000	Fiji	82 145
16	Cameroon	4 287 177	Papua New Guinea	580 000	Jamaica	145 059	Côte d'Ivoire	71 772
17	Sierra Leone	3 520 000	Madagascar	1 144 000	Gabon	200 000	Gabon	63 000
18	Madagascar	3 621 309	Philippines	516 366	Burkina Faso	113 345	China, Taiwan	50 000
19	Benin	3 295 785	Argentina	400 000	Venezuela	128 931	Solomon Islands	42 000
20	Rwanda	2 716 421	Democratic People's Republic of Korea	450 000	Democratic Republic of the Congo	100 000	Liberia	27500

Source: FAO (2012)

1.5 Constraints in Tropical Root and Tuber Production

Cassava is now commercially exploited in a number of products. However, the mechanization at the domestic and industrial level is required to be updated. The manual peeling of cassava root using knives is tedious and time-consuming, so there is a need to explore better methodology for cassava peeling. Moreover, the fermentation time is too long for the required profitable results, so there is still a need for research to confirm the role of fermentation in cassava processing. Not all cultivars of cassava are suitable for processing. The non-suitability of different cultivars and the conversion into value-added products by reviewing all the unwanted causes is a challenge. There is a need to investigate appropriate products from new cassava cultivars, which can be promoted in different countries. Inadequate storage facilities, high transportation costs and poor access to information on processing and marketing have also been identified as severe problems by the majority of processors in different areas of the world.

One major constraint for large-scale, commercial production of yam is the quantity of tubers needed for seed. About 30% of yam must be set aside for this task (Kabeya *et al.*, 2013). Another constraint for yam production is the need for staking material. Yam tubers grow deep in the ground, therefore harvesting becomes a difficult process. It is estimated that about 40% of the total costs of yam production is for labor (Eyitayo *et al.*, 2010). Yams are affected by many pests and pathogens, including insects, nematodes, fungal and bacterial diseases, and viruses.

There are constraints that restrict the scope of taro cultivation and production. The major constraints are taro leaf blight disease and taro beetle. These diseases are the major hindrances to the development of taro export trade in a number of countries, and in some cases threaten the internal food supply (Frison and Lopez, 2011). Therefore, effective controlling measures are required to be developed and disseminated to farmers. Taro production is also labor-intensive and is difficult to transport. At present, the bulk of taro produced is handled and marketed as the fresh corm. Taro corms contain a high moisture content, which makes them unable to be stored for more than a few days at room temperature.

Taro corms do not possess any particular shape at the time of harvesting, thereby creating difficulties in various unit operations like peeling, cutting, etc. There is a lot of variation in the internal color of taro corms as it ranges from yellow, white to a certain blend of colors which further depend on various cultural practices. Poi manufacturers like their products to be as purple-colored as possible, whereas the creamy white color is appreciated in the Asian region in the preparation of vegetables. The texture of taro corms varies within themselves, when exposed to certain processing operations like cooking. The outer portions are not as starchy as the center portions, hence the portions differ in specific gravity. This particular phenomenon poses a serious problem if taro corms are processed into chunks and patties, requiring a uniform texture (Hollyer and Sato, 1990).

The acridity principle in the taro corms and leaves also poses certain problems. The degree of acridity varies within different varieties. But proper treatment can provide the solution to resolve this problem (Kaushal *et al.*, 2012). The shelf life of fresh taro corms ranges from two or three weeks to several months, depending on the source of information (Patricia *et al.*, 2014). Taro deteriorates rapidly as a result of its high moisture content, but it has been estimated to have a shelf life of up to one month if undamaged and stored in a cool, shady area (Baidoo *et al.*, 2014).

The tubers of the elephant foot yam (*Amorphophallus paeoniifolius*) are highly acrid and cause irritation to the throat and mouth due to the calcium oxalate present in the tubers (orissa.gov.in). A systematic strategy needs to be adopted to preserve the product for farmers who depend mostly on commission agents to procure seed material, as well as to sell the harvested produce. In general, the major constraints in production of tropical roots and tubers are lack of automation, inadequate processing equipments, improper packaging, poor storage techniques, limited prospects of marketing and poor keeping quality.

1.6 Classification and Salient Features of Major Tropical Roots and Tubers

Tropical roots and tubers exist in different forms. The classification and their salient features are presented in Table 1.5.

1.7 Composition and Nutritional Value

Roots and tubers are one of the cheapest sources of dietary energy, in the form of carbohydrates. Their energy value is comparatively low when compared to cereals due to their higher amount of water. Because of the low energy content of roots and tubers as compared to cereals, it was earlier considered they were not suitable as baby foods. The nutritional composition of roots and tubers varies from place to place, depending on various factors such as climatic conditions, variety of crops and soils, etc. Carbohydrate is among the main nutrients, which dominate in roots and tubers. The protein content is low (1–2%) and in almost all root proteins, sulfur-containing amino acids are the limiting amino acids (FAO, 1990). Cassava, sweet potato and yam may contain little amounts of vitamin C. whereas yellow varieties of sweet potato, cassava and yam also contain β-carotene.

Vitamin C occurs in major and appropriate amounts in almost all tropical roots and tubers. The level may be reduced during cooking unless skins and cooking water are also used (Krieger, 2010). Most of the roots and tubers contain small amounts of the B complex vitamins, which act as a co-factor in the oxidation of food and production of energy. Sweet potato has high content of vitamins A, C and antioxidants that can help in preventing various diseases such as heart disease and cancer, enhance nutrient metabolism, bolster the immune system and even slow aging by promoting good vision and healthy skin. It is also an excellent source of manganese, copper, iron, potassium and vitamin B_6 (IICA, 2013). Taro is a good source of potassium. The leaves of cassava and sweet potato can be cooked and eaten as a vegetable. The leaves contain appreciable amounts of functional constituents, vitamins and minerals such as β-carotene, folic acid and iron, which may provide protection against various diseases. The dry matter of roots is made up mainly of carbohydrate, usually 60–90% (Ezeocha and Ojimelukwe, 2012).

Yam is composed mainly of starch (75–84% of the dry weight) with small amounts of proteins, lipids and vitamins and is very rich in minerals (Shin *et al.*, 2012). It is a good source of inulin, which is a form of sugar with a low calorific value with immense

Table 1.5 Tropical roots and tubers: salient features

Tropical root and tuber	Classification	Salient Features
Taro	(i) *Colocasia esculenta* (L.) Schott var. *esculenta* (ii) *Colocasia esculenta* (L.) Schott var. *antiquorum* (iii) *Xanthosoma sagittifolium*	**Genus:** *Colocasia* **Family:** *Araceae* **Scientific name**: *Colocasia esculenta* ***C. esculenta* var. *esculenta***: The variety (dasheen) has large cylindrical central corm. ***C. esculenta* var. *antiquorum***: This is a small globular central corm as compared to *C. esculenta*, with relatively large cormels arising from the corm itself. This variety is referred as the eddoe type of taro. ***Xanthosoma sagittifolium:*** Popularly known as Macabo in Africa, has smaller edible *cormels* about the size of potatoes. Its corms and cormels are rich in starch.
Sweet potato	(i) Orange/copper skin with orange flesh (ii) White/cream skin with white/cream flesh (iii) Red/purple skin with cream/white flesh	**Genus:** *Ipomoea* **Family:** *Convolvulaceae* **Scientific name:** *Ipomoea batatas* **Orange/copper skin with orange flesh type:** They have high beta-carotene content and are quick growers, which may become too big with longer growing periods. **White/cream skin with white/cream flesh type:** White sweet potatoes are also called camote, batata or boniato. The outside skin of the white sweet potato is either a brownish-purple or a reddish-purple color, whereas the inside flesh is white or cream colored. It can produce good yield in a relatively short growing period (4 months), which is important for cold regions. Long and curved sweet potatoes are produced especially in sandy soils. **Red/purple skin with cream/white flesh type:** It is mainly used in recipes that require mashed or grated sweet potatoes such as pies, breads and cakes, due to its high moisture content. It requires a growing period of 5 months to produce a good yield.

(*continued overleaf*)

Table 1.5 (*continued*)

Tropical root and tuber	Classification	Salient Features
Yam	(i) White yam (*Dioscorea rotundata* Poir) (ii) Yellow yam (*Dioscorea cayenensis* Lam.) (iii) Water yam (*Dioscorea alata* L.) (iv) Bitter yam (*Dioscorea dumetorum*)	**Genus:** *Dioscorea* **Family:** *Dioscoreaceae* **Scientific name:** *Dioscorea spp*. **White yam (*Dioscorea rotundata* Poir)**: This is cylindrical in shape, having smooth and brown skin with a white and firm flesh. It is widely grown and preferred yam species. **Yellow yam (*Dioscorea cayenensis* Lam.)**: The yellow yam has a longer vegetation period and a shorter dormancy as compared to white yam. It has acquired the name from its yellow flesh **Water yam (*Dioscorea alata* L.)**: This is the most widely spread out all over the globe. It is only second to the white yam in popularity in Africa. This tuber is cylindrical in shape, having white colored flesh and watery texture. **Bitter yam (*Dioscorea dumetorum*)**: This is also referred as the trifoliate yam because of its leaves. It has a bitter flavor and its flesh hardens if not cooked properly soon after harvesting. Some of its cultivars are highly poisonous.
Cassava	(i) Sweet and bitter cassava (ii) Yellow cassava	**Genus:** *Manihot* **Family:** *Euphorbiaceae* **Scientific Name:** *Manihot esculenta* **Sweet and bitter cassava**: Sweet cassava roots contain comparatively much lesser hydrogen cyanide as compared to bitter cassava. These varieties need to be detoxified before consumption through different types of treatments. Sweet cassava produces higher yields and requires lesser processing as compared to bitter cassava. **Yellow cassava:** It is similar to ordinary varieties of cassava (*Manihot esculenta*), but it has yellow flesh inside the root. It does not need nutrient-rich soils or extensive land preparation and does not suffer during droughts.

Table 1.5 (*continued*)

Tropical root and tuber	Classification	Salient Features
Elephant foot yam		**Genus:** *Amorphophallus* **Family:** *Araceae* **Scientific name:** *Amorphophallus paeoniifolius* The elephant foot yam originated in Southeast Asia. *Amorphophallus* species are herbs and only a single leaf emerges from the tuber, consisting of a vertical spotted petiole and a horizontal leaf-blade (lamina). Its popular varieties are Gajendra, Kusum and Sree Padma.
Giant taro		**Genus:** *Alocasia* **Family:** *Araceae* **Scientific name:** *Alocasia macrorrhizos* The giant taro originates from rainforests of Malaysia to Queensland. The varieties recognized in Tahiti are the Ape oa, haparu, maota and uahea. It is edible, if cooked for adequate time, but its sap irritates the skin due to calcium oxalate crystals, or raphides, which are needle-like crystals.

benefits to diabetics. Its phyto-nutritional profile comprises of dietary fiber and antioxidants, in addition to traces of minerals and vitamins (Slavin *et al.*, 2011).

Plant carbohydrates mainly include celluloses, gums and starches. The properties of starch grains affect the processing qualities and digestibility of tropical roots/tubers. In addition to starch and sugar, root and tuber crops also contain some non-starch polysaccharides; such as celluloses, pectins and hemicelluloses, along with other associated structural proteins and lignins, which are collectively referred to as dietary fiber (FAO, 1990). The protein content and quality of tropical roots and tubers (Table 1.6) is variable, ranging from 1–2.7%. Taro has the highest protein content (2.2%) among the given roots and tubers (Table 1.6). However, the protein content is higher in the leaves (4.0%) than the tubers. The comparison of nutritional profiles of various tropical roots and tubers is illustrated in Table 1.6.

Tropical roots and tubers exhibit very low lipid content. The lipids are mainly structural lipids of the cell membrane, which enhance cellular integrity and help to reduce enzymatic browning (FAO, 1987). Most of the lipids present in tropical roots and tubers consist of equal amounts of unsaturated fatty acids, linoleic and linolenic acids and the saturated fatty acids, stearic acid and palmitic acid, etc.

Most of the roots and tubers are good sources of potassium and consist of lower amounts of sodium. This makes them particularly valuable and distinguishable in the

Table 1.6 Comparison of nutritional profile of various tropical roots and tubers

Roots and tubers	Food energy (kilo-joule)	Moisture (%)	Protein (g)	Fat (g)	Fiber (g)	Total CHO and fiber (g)	Ash (g)
Cassava	565	65.5	1.0	0.2	1.0	32.4	0.9
Sweet potatoes (white)	452	72.3	1.0	0.3	0.8	25.1	0.7
Sweet potatoes (yellow)	481	70.0	1.2	0.3	0.8	27.1	0.7
Yam	452	71.8	2.0	0.1	0.5	25.1	1.0
Taro and tannia	393	75.4	2.2	0.4	0.8	21.0	1.0
Giant taro	255	83.0	0.6	–	–	14.8	–
Elephant foot yam	339	78.5	2.0	–	–	18.1	–
Taro leaves	255	81.4	4.0	–	–	11.9	–
Sweet potato tips	–	86.1	2.7	–	–	–	–

Source: FAO, (1972)

diet of patients suffering from high blood pressure, who require limited sodium intake (Valli *et al*., 2013). In such cases, the high potassium to sodium ratio may provide an additional health benefit. Yam can supply a substantial portion of the manganese and phosphorus and to a lesser extent the copper and magnesium.

1.8 Characteristics of Tropical Roots and Tubers

High respiration rate, high moisture content (70–80%) and larger unit size (100 g–15 kg) are the general characteristics of tropical roots and tubers. In addition, their soft texture and heat production rate of approximately 0.5–10 MJ/ton/day and 5–70 MJ/ton/day at 0°C and 20°C respectively are one of their distinct characteristics (FAO, 1993). These are perishable, having a limited shelf life of several days to fewer months, but have a better yield under adverse conditions as compared to other crops. The losses are usually caused by rotting (bacteria and fungi), senescence, sprouting and bruising (Atanda *et al*., 2011). The comparison of various tropical roots and tubers is given in Table 1.7.

1.9 Anti-nutritional Factors in Roots and Tubers

Roots and tubers mostly contain variable amounts of anti-nutritional factors such as oxalates, phytates, amylase inhibitors, trypsin inhibitors, etc. The cultivated varieties of most of the edible roots and tubers, except cassava (which contains cyanogenic glycosides) do not possess any serious toxins, whereas the wild species may contain toxic principles, therefore must be correctly processed with appropriate methodology before consumption. However, some of these wild species serve as a useful reserve when food scarcity arises. The local people have developed suitable techniques to detoxify the roots and tubers before consumption (FAO, 1990). The various anti-nutritional factors present in roots and tubers along with their mode of elimination are presented in Table 1.8.

Table 1.7 Comparison of various tropical roots and tubers

Factor	Cassava	Taro	Sweet potato	Yam	Elephant foot yam
Plant Family	*Euphorbiaceae*	*Araceae*	*Convolvulaceae*	*Dioscoreaceae*	*Araceae*
Chromosomes	2n = 36	2n = 22, 26, 28, 38, and 42	2n = 90	2n = 20	2n = 26
Flower	Monoecious	Monoecious	Monoecious	Dioecious	Monoecious
Origin	Tropical America	Indo-Malayan	Central or South America	West Africa or Asia	Southeast Asia
Edible part	Root, leaves	Corm, cormels, leaves and petioles	Root, leaves	Tuber	Tuber
Actualization	Firm	Rough, thick skin and doughy texture	Smooth, with thin skin	Rough, scaly	Rough, thick skin
Shape	Large and irregular	Large, starchy, spherical underground tubers	Short, blocky, tapered ends	Long, cylindrical, some with "toes"	Large and round
Taste	Sweet or bitter	Starchy	Sweet	Starchy	Starchy
Beta carotene	Usually high in yellow cassava.	Leaves contain high levels of beta carotene.	Usually high	Usually very low	Usually high
Annual, biennial, or perennial	Perennial	Perennial	Perennial	Perennial	Perennial
Plant	Woody plant with erect stems	Large, starchy, spherical underground tubers. The large leaves of the taro are commonly stewed.	Plant bears alternate heart-shaped or palmately-lobed leaves.	Monocot (a plant having one embryonic seed leaf).	Tropical tuber crop, grown for its round corm. The stems can be 1–2 m tall.

(*continued overleaf*)

Table 1.7 (*continued*)

Factor	Cassava	Taro	Sweet potato	Yam	Elephant foot yam
Leaves	Simple lobed leaves up to 30 cm in length, but may reach 40 cm.	Each leaf is made up of an erect petiole and a large lamina.	Ovate-cordate, borne on long petioles, palmately veined, angular or lobed.	Leaves are veined with lengthy stems that are attached to the vines of the plant.	About 50 cm long and consist of several oval leaflets.
Root/Tuber description	Nutty flavored, starchy Root	Tubers are rounded, about the size of a tennis ball; each plant grows one large tuber, often surrounded by several smaller tubers.	The root is long and tapered, with a smooth skin, whose color may be yellow, orange, brown, red and purple. The flesh color ranges from white, pink, red, yellow, violet, orange and purple.	Tuber can be cylindrical, curved or lobed, with brown, grey, black or pink skin and white, orange or purplish flesh.	Round corms are usually 3–9 kg, depending on the number of seasons that the crop is grown before harvest.
Climate and weather	Survivor crop capable of withstanding long periods of dry weather.	Can be grown in the fields where water is abundant.	The plant does not tolerate frost. It grows best at 24°C in abundant sunshine and warm nights. Annual rainfalls of 750–1,000 mm are considered most appropriate.	It is tolerant to frost conditions and can be grown in much cooler conditions as compared to other tubers.	It grows well in hot and humid climate. Well drained, fertile and sandy loam soil is ideal for its production. Stagnant water at any stage can affect its production.
Height	1–2 m	1–2 m	0.30–0.46 m	1–3 m	1–2 m

Propagation	From stem cuttings	By offshoots from the mother corm	Transplants/vine cuttings	Tuber pieces	Small corms (cormels) or buds are used for this purpose. These are produced below ground level.
Diseases	Bacterial blight, cassava frogskin disease, Viral diseases, etc.	Leaf blight, Erwinia soft rot, shot hole leaf disease	Bacterial stem and root rot, bacterial wilt, soil rot	Yam Anthracnose, Yam Mosaic Virus, Water yam virus, other foliage diseases	Foot rot, Pythium root rot, Amorphophallus Mosaic and leaf blight
Harvesting	It is commonly harvested by separating the stem from the plant and then pulling out the roots from the ground.	Taro tubers are harvested in nearly 200 days. The leaves can be picked after the first leaf is open.	Harvested at any time after they have reached a suitable size (generally 3–4 months). Their flavor and quality will improve with colder weather. Can even wait until the frost has blackened all of the vines before harvesting.	Harvesting is done before vines become dry and hard. After 7–12 months growth, tubers are harvested.	Corms can be dug up by hand. Take about 6–7 months to mature. Leaf yellowing and drying up of plants indicate that the crop is ready to harvest. Harvesting can begin after 5–6 months.

Table 1.8 Anti-nutritional factors in roots and tubers and their mode of elimination

Roots/ tubers	**Anti nutritional factor and their levels**	**Mode of Elimination**	**Reference**
Raw Bitter Cassava	• Saponin: 730 mg/kg • Oxalate: 49 mg/kg • Phytate: 12 320 mg/kg • cyanide: 14 300 mg/kg	Fermentation, pressing, frying, cooking or drying	Amira *et al*. (2014)
Dried Bitter Cassava	• Saponin: 630 mg/kg • Oxalate: 32 mg/kg • Phytate: 8,770 mg/kg • Cyanide: 9,140 mg/kg	Fermentation, pressing, frying, cooking or drying	Amira *et al*. (2014)
Raw taro	• Oxalate: 156.33 mg/100 g • Phytate: 85.47 mg/100 g	Soaking and boiling	Alcantara *et al*. (2013)
Yam: *D. alata*	• Total free phenolics: 0.68 g/100 g • Tannins: 0.41 g/100 g • Total oxalate: 0.58 g/100 g • Hydrogen cyanide: 0.17 mg/100 g • Trypsin inhibitor: 3.65 TIU/mg • Amylase inhibitor: 6.21 AIU/mg soluble starch	Moist heat treatment (for amylase and trypsin inhibitor) Soaking followed by cooking before consumption (for phenolics, tannins, hydrogen cyanide and total oxalate)	Shajeela *et al*. (2011)
Yam: *D. bulbifera var vera*	• Total free phenolics: 2.20 g/100 g • Tannins: 1.48 g/100 g • Total oxalate: 0.78 g/100 g • Hydrogen cyanide: 0.19 mg/100 g • Trypsin inhibitor: 1.21 TIU/mg • Amylase inhibitor: 1.36 AIU/mg soluble starch	Moist heat treatment (for amylase and trypsin inhibitor) Soaking followed by cooking before consumption (for phenolics, tannins, hydrogen cyanide and total oxalate)	Shajeela *et al*. (2011)
Elephant Foot Yam	• Soluble oxalate: 13.53 mg/100 g	Soaking and boiling	NPARR (2010)
Boiled sweet potato	• Phytate: 0.88 mg/100 g • Oxalate: 167.15 mg/100 g • Tannin: 0.68 mg/100 g	Cooking	Abubakar *et al*. (2010)

TIU: Trypsin inhibitor unit, AIU: Amylase inhibitor unit

1.9.1 Cassava

The residual level of cyanogens in cassava products differ in different varieties, depending upon the nature and duration of the various processing techniques (Montagnac *et al*., 2008). Linamarin, a cyanogenic glycoside, occurs in varying amounts in different parts of the cassava plant (Obazu, 2008). It often co-exists as methyl-linamarin or lotaustralin. Linamarin may become converted into hydrocyanic acid or prussic acid when it comes into contact with an enzyme called linamarase, which is released on the rupturing of cassava cells. In the absence of this enzyme, linamarin is considered a stable compound which is not changed, even with boiling (FAO, 1990). If it is absorbed from the gut into the blood, it is probably excreted unchanged without causing any harm to the organism (Philbrick *et al*., 1977). Ingested linamarin can liberate cyanide into the gut during digestion process. However, proper processing and cooking methods can reduce the cyanide content to non-toxic levels. Sweet cassava roots contain less than 50 mg/kg HCN on a fresh weight basis, whereas the bitter variety may contain up to 400 mg/kg (Kwok, 2008). In dry tubers, cyanide residues can be in the range of 30–100 mg/kg (Agbidye, 1997). As per the African Organization for Standardization, cassava-based products, especially flour, should have the acceptable limit of cyanide content, 10 mg/kg. Simple boiling of fresh root pieces is not always reliable since the cyanide may only be partially liberated and only a part of linamarin may be extracted in the cooking water. The reduction of cyanides depends upon the treatment method. The cassava roots, when placed in cold water (27°C) or boiling water (100°C) for 30 min, has a reduced cyanide content of 8% or 30% of its initial value respectively (Essers, 1986).

Sun-drying processing techniques are not considered efficient for detoxification of cassava roots, because they do not effectively reduce cyanide content in a short interval of time. Sun-drying processing techniques reduce only 60–70% of the total cyanide content present in the first two months of preservation (FAO, 1990). Fermentation is also considered an effective method of the detoxification process. The liberated cyanide is dissolved into the water when fermentation is effected by prolonged soaking and evaporates upon drying of the fermented cassava (FAO, 1990). Ighu (a processed cassava product) is processed manually using metallic shredding plates, which are moved vigorously by hand on the surface of peeled steamed cassava by reciprocating action. Ighu samples have lower HCN content, which makes this product safe for human consumption. The HCN content of the dry Ighu varies from 8.20–9.83 mg/kg (Iwe and Agiriga, 2013). The cyanide content of processed cassava tubers (garri) is significantly reduced after 48 hours of fermentation (Chikezie and Ojiako, 2013).

1.9.2 Sweet Potato

The dietary fiber content, particularly hemicelluloses, in sweet potato (variety Tinipa) has been reported to be 4.5% of the total carbohydrate, which is twice the amount of free sugars (2.41%) (Roxas *et al*., 1985). *In-vitro* degradation of hemicellulose by intestinal bacteria may result in increased breath production of hydrogen, one of the gases produced during flatus production. Thus, a high level of food fiber has a great potential for inducing flatulence (Salyers *et al*., 1978). On the other hand, raffinose in sweet potato is also considered one of the sugars, responsible for flatulence (FAO, 1990). However, further research is required to verify the role of crude fiber/raffinose in foods including sweet potato in producing flatulence. The sugars which occur in plant tissues, stachyose, raffinose and verbascose, are not digested in the upper digestive intestinal tract, and therefore are fermented by colon bacteria to yield the flatus gases, hydrogen and carbon dioxide (FAO, 1990). The level of sugars present depends upon the cultivar. Lin and Chen (1985) established that sweet potato shows trypsin inhibitor activity (TIA) ranging from 20–90% in different varieties.

A major anti-nutrient of sweet potato is the presence of trypsin and proteinase inhibitors. Inactivation of trypsin inhibitors by heat treatment improves the protein quality and thereby increases the nutritive quality of the sweet potato (Senanayake *et al.*, 2013). Roasting greatly lowers the level of trypsin inhibitor activity compared to boiling. The highest level of trypsin inhibitor activity is recorded in the raw tubers, and the reduction is observed upon processing (Omoruyi *et al.*, 2007). The trypsin inhibitor content of sweet potato can be correlated with the protein content. Heating to 90°C for several minutes completely removes trypsin inhibitors. TIA in sweet potato may be a contributory factor in the disease enteritis necroticans (Lawrence and Walker, 1976). However, this appears doubtful because sweet potatoes contain anti-nutrients, but these occur at very low levels, and most of the time our bodies are perfectly able to process them.

In response to injury, or exposure to infectious agents, sweet potato produces certain metabolites. Fungal contamination of these tubers by *Ceratocystis fimbriata* and several *Fusarium* species leads to the production of ipomeamarone, a hepatoxin and other metabolites like 4-ipomeanol, pulmonary toxins (FAO, 1987). Baking destroys only 40% of these toxins. The peeling of blemished or diseased sweet potatoes from 3–10 mm beyond the infested area is sufficient to remove most of the toxin (Catalano *et al.*, 1977). Various methods of processing such as soaking and cooking have an effective result in reducing the anti-nutrients of foods. Hydrocyanic glycoside, a toxic compound in sweet potato, can be easily destroyed by cooking (Ojo and Akande, 2013).

1.9.3 Taro

Taro is inedible when raw and considered toxic due to the presence of calcium oxalate crystals, typically as raphides. Foods produced from taro suffer from the presence of acrid factors, which may cause itchiness and considerable inflammation of tissues to consumers. Even raw leaves and petioles can cause acridity. The intensity of the acridity varies considerably among taro cultivars. Also for the same cultivar, environmental stress (such as drought or nutrient stress) during the growing season may result in higher levels of acridity.

Presumably, itchiness arises when the calcium oxalate crystals are released and inflict minute punctures to the skin when in contact with it. Bradbury and Holloway (1988) suggested that the crystals have to interact with a certain chemical on the raphide surface before acridity is experienced. The acridity factor can be reduced by different unit operations such as peeling, grating, soaking and fermentation (Pena *et al.*, 1984). Removal of the thick layer of skin may help to remove acridity. Acridity in taro root can be minimized by cooking, especially with a pinch of baking soda and by steeping taro roots in cold water overnight. Kaushal *et al.* (2012) compared the anti-nutrients in taro, rice and pigeon pea flours. Phytic acid and total polyphenol content for taro flour was 107.3 mg/100 g and 577.21 mg/100 g, respectively. The total polyphenol content in the noodles prepared from 100% taro flour was observed to be 577.21 mg/100 g (Kaushal and Sharma, 2014).

1.9.4 Yam

The edible matured yam generally does not contain any toxic principles (Coursey, 1983). Wild forms of *D. dumetorum* contain bitter principles, and hence are referred as bitter yam. The bitter principle is the alkaloid dihydrodioscorine, while that of the Malayan species, *D. hispida*, is dioscorine (Palaniswami and Peter, 2008). There are water-soluble alkaloids which, on ingestion, produce severe and distressing symptoms. The contents of the anti-nutrients (cyanide, oxalic acid, tannin, sapogenin and alkaloid of species) in wild yam are well below the FAO/WHO safety limits (Sahore *et al*., 2006).

The bitter principles of *D. bulbifera* (called the aerial or potato yam) include a 3-furanoside norditerpene called diosbulbin (FAO, 1990). Such substances are toxic and the extract finds its application in immobilizing fish to facilitate capture. The toxicity of the extract may be due to saponins. The detoxification methods for bitter cultivars may involve water extraction, fermentation and roasting of the grated tuber. Boiling possesses both a positive and negative effect on water yam. A cooking time of between 30 and 60 min at 100°C is recommended for *D. alata* (Ezeocha and Ojimelukwe, 2012). The anti-nutritional factors of yams decrease greatly during boiling rather then during than baking (Kouassi *et al*., 2010).

1.9.5 Elephant Foot Yam

The edible, mature, cultivated elephant foot yam does not contain any toxic principles (www.wikipedia.com). Calcium oxalate is present as a fine crystal resulting in itching of fingers and pricking sensation of tongue and throat. However, calcium oxalate is easily broken down thoroughly either by cooking or by complete drying. Under either of these conditions, it is safe to eat. It can also be consumed after it is washed well and boiled in tamarind water or butter milk.

1.10 Applications of Tropical Roots and Tubers

The various applications of tropical roots and tubers include the following:

1.10.1 Animal Feed

Nearly half of the sweet potatoes produced in Asia are used for animal feed. The vines have a lower carbohydrate content but higher fiber and protein and their principle nutritive value is a source of vitamins and protein. The sweet potato vines can serve as a nutritive and palatable feed for cattle. The unmarketable and poorly developed tubers can also be utilized in animal feed. Cassava chips are utilized as cattle feed and poultry feed. In the animal feed industry, cassava is one of the most abundantly used food ingredients in place of cereal grain. In some parts of the world, sweet potato and cassava tubers, taro corms and petioles are chopped, boiled and fed to pigs. However, sweet potato vines and cassava leaves are also used for feeding cattle and pigs. Taro peels and wastes are also fed to domestic livestock in various countries.

1.10.2 Industrial

Sweet potato and cassava are used for different industrial products. Sweet potatoes are used in various industrial processes to produce alcohol and processed products such as noodles, candy, desserts and flour (www.encyclopedia.com). A sizeable portion of cassava goes into industrial uses. Cassareep is the product of cassava obtained from the juice of bitter cassava that is boiled to a sufficiently thick consistency and flavored with certain spices (www.wikipedia.com). This cassava product is exported from Guyana and is used as a traditional recipe having its origin in Amerindian practices. Various products like sago, dextrose, glucose, alcohol, etc. are other products made out of cassava in different countries.

1.10.3 Medicinal

The leaves and roots of taro contain polyphenols, which are considered helpful to protect from cancer. Taro root has more than 17 different essential amino acids to maintain good health and is also considered a good source of vitamins and minerals that can give protection from cancer and heart disease (www.fao.org).

Like other roots and tubers, cassava is free from gluten. Gluten-free flour can be used for treating celiac disease patients. Young tender cassava leaves are a good source of dietary proteins and vitamin K. The vitamin K has a potential role in building bone mass by promoting osteotrophic activity. It also has an established role in the treatment of Alzheimer’s disease by limiting neuronal damage in the brain (www.guyanatimesgy.com).

Elephant foot yam is used in many Ayurvedic preparations. The tubers are considered to have pain-killing, anti-inflammatory, anti-flatulence, digestive, aphrodisiac and rejuvenating tonic properties. The tuber is particularly used to cure health problems such as inflammation, coughs, flatulence, constipation, anaemia, haemorrhoids and fatigue. The tuber does not cause gastrointestinal problems (Basu *et al.*, 2014).

1.10.4 Foods

Sweet Potato The sweet potato is a rich source of β-carotene. The tuber contains many essential vitamins such as vitamin B_5, vitamin B_6, vitamin B_1, niacin and riboflavin. These vitamins function as co-factors for various enzymes during metabolism. It provides a good amount of vital minerals such as iron, calcium, magnesium, manganese and potassium, which play important roles in protein and carbohydrate metabolism. Examples of sweet potato applications are:

- Sweet potato has been processed into chips (crisps) in much the same way as potato and the product is now popular in Asia.
- In Japan, about 90% of the starch produced from sweet potato is used to manufacture syrups, lactic acid beverages, bread and other foods. As a puree, it is used in pie fillings, sauces (e.g. tomato sauce in Uganda), frozen patties, baby foods and in fruit-flavored sweet potato jams (e.g. with pineapple, mango, guava and orange).
- Whole, halved, chunks or pureed sweet potatoes are canned. Cubes, French fries, mash, halves, quarters and whole roots can be frozen (Troung *et al.*, 2011).

- Mashed sweet potato can be used as an ingredient in ice cream, baking products and desserts, as a substitute for more expensive ingredients. Sweet potato flour can be used as a supplement for wheat flour in baking bread, biscuits and cakes.

Taro Taro root has a low glycemic index and is a good source of vitamin C. Taro starch is one of the few commercially available starches with a smaller granule size. The starches can be good for dusting applications (useful in candy manufacture) and flavor applications as a carrier substance. Taro starch may lend itself to specialty markets such as the food, plastic or cosmetic industries. Examples of taro applications are:

- Taro leaves are usually boiled and prepared in different ways by mixing with other condiments followed by frying with spices. The largest quantity of taro produced in the Asia–Pacific region is utilized starting from the fresh corm or cormel. They are boiled, baked, roasted or fried and consumed in conjunction with fish, coconut preparations, etc.
- Taro corms, which are not suitable for the fresh market or for value-added product, can be converted into taro flour to be used for different food formulations such as taro bread, taro cookies, cake (Kumar *et al*., 2015), baby food, pasta, noodles (Kaushal and Sharma, 2014), instant or flavored poi, or other products. Taro flour can also be used as a thickener for soups and other preparations.
- Taro corms contain about 10% mucilage on a dry weight basis and therefore have the potential to be used in the gum or dietary fiber market, but these areas need to be explored. Another processed, packaged form of taro is poi, a sour paste made from boiled taro. Its production and utilization is common in the Hawaiian Islands. Achu, another highly digestible food obtained from taro, is commonly consumed in Cameroon.
- Processed and storable forms of taro are taro chips (snacks) in the Asia–Pacific region. They are usually made by peeling the corm, washing, slicing into thin pieces and blanching. The pieces are fried in vegetable oil, allowed to cool and drain and then packaged. While taro chips are made in a number of countries, their availability is sporadic and quantities produced are small. Pacific Islanders consume a large amount of taro in baked or boiled form, with or without cream. Moreover, ready-to-eat taro chunks and patties are also available in the Pacific Islands.

Cassava Cassava has nearly twice the calories than potatoes, perhaps highest for any tropical starch rich tubers and roots (www.naturalnews.com). These calories mainly come from sucrose forming the bulk of the sugars in the roots, accounting for more than 69% of the total sugars. There are four major processed forms of cassava: meal, flour, chips and starch. In Nigeria, the main food products of considerable domestic importance are gari, lafun and fufu or akpu (Taiwo, 2006).

- Gari is the most common food product processed from cassava in West Africa. It is usually eaten in the form of snacks by soaking in water, or in the meal form where it is reconstituted by stirring in hot water to form dough which is eaten with soup (Udoro, 2012). Lafun is fermented cassava flour which is prepared as a stiff porridge using boiled water. It is processed from cassava by peeling, cutting, submerged fermentation, dewatering, sun-drying and milling (Oyewole and Sanni, 1995).

- Fufu is a meal prepared from soaked fermented cassava in Eastern Nigeria. The cooked mass is pounded with a mortar and pestle to produce a paste (fufu) that can be eaten with sauce, soups or stews (Balagopalan, 2002). Cassava chips are unfermented, dry products of cassava. In some parts of the world, cassava chips are converted into common food products such as starch, flour, fufu and gari. In addition, cassava applications are in different products such as extruded products, bread, fermented foods, drinks, cakes, etc.

Yam The edible part of yam is chiefly composed of complex carbohydrates and soluble dietary fiber. In addition, being a good source of complex carbohydrates, it regulates blood sugar levels and, for the same reason, is recommended as a low glycemic index healthy food. The tuber is an excellent source of the B-complex group of vitamins and minerals:

- The processing and utilization of yam includes starch, poultry and livestock feed, production of yam flour and instant-pounded yam flour (Olatoye *et al*., 2014). Traditionally, processed yam products are made in most yam-growing areas, usually as a way of utilizing tubers that are not fit for storage. Usually fresh yam is peeled, boiled and pounded until a sticky elastic dough is produced (Shin *et al*., 2012), which is referred as pounded yam or fufu.
- The nutritional value of yam flour is the same as that of pounded yam. The yam flour is rehydrated and reconstituted into fufu and eaten with a soup containing fish, meat and/or vegetables. The manufacture of fried products from *D. alata* has also been attempted recently.
- Instant pounded yam flour (IPYP), which is a processed white powdery form of yam (dehydrated yam flour), can be produced in a desiccating machine (Olatoye *et al*., 2014). Preservation of yam in brine has been attempted, but with little success. Attempts to manufacture fried yam chips, similar to French fried potatoes have been reported.

Elephant Foot Yam Elephant foot yam is a good source of minerals such as potassium, magnesium and phosphorous, as well as trace minerals like selenium, zinc and copper. It is an important tuber crop of the tropics grown as a vegetable. Petioles are also used as a vegetable. They are used in combination with other vegetables for the preparation of various dishes. Frying is also a common practice for their utilization:

- They can be used in curries, made into chips, soups, stews and casseroles. Food products like noodles, pickles, bread, etc. have also been attempted with the incorporation of elephant foot yam.

1.11 New Frontiers for Tropical Roots and Tubers

The production and marketing of the major roots and tubers share common themes, trends and prospects. However, the majority of the smallholders cultivating these crops do so under less than optimal conditions, with yields below world average and a low degree of market organization. In addition, there is a disjointed, unorganized approach to the development of the trade in such products, particularly

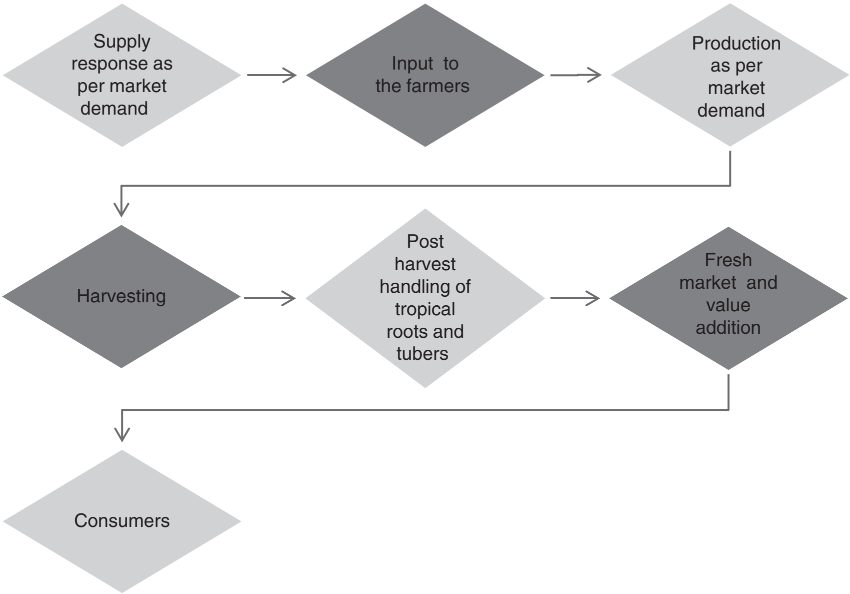

Figure 1.3 Commodity value scheme for tropical roots and tubers.

the commodity value chains. There is a need to focus on the regional market, and better adaptive technology transfer and upgrading of existing processing and product development technologies. Efforts should be made to promote new technologies, appropriate for use by the rural population, to produce a variety of processed foods. This strategy will generate employment and improve incomes in rural areas.

Initiatives need to be taken, including the characterization of various varieties of tropical roots and tubers found in various countries and value addition. The effective focus is needed to prioritize improving productivity, pest and disease management and post-harvest practices to increase the shelf life of tropical roots and tubers. The commodity value chain scheme for tropical roots and tubers is presented in Figure 1.3. The value chain focuses upon the production and harvesting of roots and tubers as per the calculated demand, along with the focus upon post-harvest handling and value addition. The proper implementation of a commodity scheme will assist food security, better income for farmers and improved communication. The different stages shown in Figure 1.3 require systematic efforts in totality to bring roots and tubers on a commercial scale parallel to cereals.

1.12 Future Aspects

Roots and tubers are essential components of the diet in many countries. In Africa, it has been estimated that nearly 37% of the dietary energy comes from cassava. Roots and tubers have the potential to provide more dietary energy per hectare than cereals. Taro and cassava can be grown in tropical climates all the year round, which may prove beneficial to provide increased food security. Many food-deficit countries are forced to import large quantities of grain to meet local production shortfalls, which places a burden on the national exchequer.

Despite research on roots and tubers, many issues still need to be addressed such as improved production, energy management and post-harvest handling and utilization in foods and feed. Therefore, strategies need to be developed to address these issues so that root and tubers can play a better role in ensuring food security, sustainable farming and sustainable livelihood development. However, low productivity, limited value addition and poor access to markets are the issues required to be tackled globally. With the current global shortage of food grains coupled with the ever-increasing human population, the root crops as a whole will certainly be the answer in future to food crisis, because of their high productivity and ability to grow under rain-fed and adverse climatic conditions.

Research and development along with the commercialization of roots and tubers is limited and its potential has not been tapped. Therefore, a well-designed, integrated strategy of production, processing and marketing to stimulate increased utilization is needed. The system can be made more effective regarding the research on tropical roots and tubers by creating database development for production, processing, trade and consumption. Moreover, integrated pest management and public awareness efforts, involving the private sector in research and research support and geographical information systems are systematically required. In addition, physicochemical, functional and organoleptic evaluation of foods in relation to consumer preferences, life-cycle analysis of environmental impacts related to processing of tropical roots and tubers, and optimized process for reducing the anti-nutrients in tropical roots and tubers are some of the areas that need proper attention and implementation. These aspects need to be designed to provide millions of small-scale farmers with the tools, technologies and solutions that could help to transform various tropical roots and tubers into food security crops, foreign exchange earners and vehicles for economic development.

References

Abubakar, H.N, Olayiwola, I.O., Sanni, S.A. and Idowu, M.A. (2010) Chemical composition of sweet potato (*Ipomea batatas* Lam) dishes as consumed in Kwara state, Nigeria. *International Food Research Journal*, **17**: 411–416.

Adeleke, R.O. and Odedeji, J.O. (2010) Functional properties of wheat and sweet potato flour blends. *Pakistan Journal of Nutrition*, **9**: 1775–1991.

Agbidye, J.T. (1997) *Cyanide metabolism in sulfur amino acid deficiency: Relevance to cassava related neurodegenerative diseases*. A thesis submitted to Oregon State University, Corvallis, OR.

Aidoo, R. (2009) An analysis of yam consumption patterns in Ghanaian urban communities. A dissertation submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Alcantara, R.M., Hurtada, W.A. and Dizon, E.I. (2013) The nutritional value and phytochemical components of taro (*Colocasia esculenta* L. Schott) powder and its selected processed foods. *Nutrition and Food Sciences*, **3(3)**: 207–213.

Amankwaah, V.A. (2012) Phenotypic and molecular characterization of released and elite sweet potato varieties in Ghana compared with virus-tested putative ramets. A thesis submitted to the School of Graduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Amira, P.O., Daramola, S.A. and Atolani, S.T. (2014) Effect of drying on some anti-nutritional factors present in Bitter Cassava (*Manihot utilisima*) and Sweet Cassava (*Manihot palmata*). *International Journal of Engineering Science and Innovative Technology*, **3(4)**: 368–372.

Atanda, S.A., Pessu, P.O., Agoda, S., Isong, I.U. and Ikotun, I. (2011) The concepts and problems of post-harvest food losses in perishable crops. *African Journal of Food Science*, **5(11)**: 603–613.

Baidoo, E.A., Akonor, P.T. and Tortoe C. (2014) Effect of pre-treatment and storage conditions on the physicochemical properties of taro (*Colocasia esculenta* [L.] Schott) flour. *International Journal of Food Science and Nutrition Engineering*, **4(4)**: 91–97.

Balagopalan, C. (2002) Cassava utilization in food, feed and industry, in: *Cassava: Biology, Production and Utilization* (eds R.J. Hillocks, J.M. Tresh and A.C. Belloti), CIAT, Colombia, pp. 301–318.

Basu, S., Das M., Sen, A., Choudhury U.R. and Datta, G. (2014) Analysis of complete nutritional profile of *Amorphophallus campanulatus* tuber cultivated in Howrah district of West Bengal, India. *Asian Journal of Pharmaceutical and Clinical Research*, **7(3)**: 879–885.

Beddington, J. (2009) Food security: Contributions from science to a new and greener revolution. *Philosophical Transactions of the Royal Society*, **365(1537)**: 61–71.

Bradbury, J.H. and Holloway, W.D. (1988) Chemistry of tropical root crops: Significance for nutrition and agriculture in the Pacific. Canberra, Australian Centre of International Agriculture Research, ACIAR, Monograph No. 6, pp. 17–201.

Castillo, C.P. del. (2011) *Report on roots, tubers and bananas for food security and income*. Consortium Research Program, CGIAR Consortium Board, Washington, DC.

Catalano, E.A., Hasling, V.C., Dupung, H.P. and Costantin, R.J. (1977) Ipomeamarone in blemished and diseased sweet potatoes. *Journal of Agricultural and Food Chemistry*, **25**: 94–96.

Chikezie, P.C. and Ojiako, O.A. (2013) Cyanide and aflatoxin loads of processed cassava (*Manihot esculenta*) tubers (Garri) in Njaba, Imo state, Nigeria. *Toxicology International*, **20(3)**: 261–267.

Coursey, D.G. (1983) Yams, in: *Handbook of Tropical Foods* (ed. H.T. Chan), Marcel Dekker, New York, pp. 555–601.

Essers, S. (1986) Development of fast detoxification methods for bitter cassava at household level in rural N.E. Mozambique. Final report for Ministry of Health of Mozambique, Mozambique, pp. 9–27.

Eyitayo, O.A., Anthony, T.O. and Theresas, I. (2010) Economics of seed yam production using Minisett technique. *Field Actions Science Report*, vol. **4**, Oyo State, Nigeria.

Ezeocha, V.C. and Ojimelukwe, P.C. (2012) The impact of cooking on the proximate composition and anti-nutritional factors of water yam *(Dioscorea alata*). *Journal of Stored Products and Postharvest Research*, **3(13)**: 172–176.

FAO (1972) Food consumption table for use in East Asia. FAO, Rome.

FAO (1987) Role of roots, tubers and plantains in food security in Latin America and the Caribbean. Committee on World Food Security, Sess. 12. Rome, pp. 8–15.

FAO (1990) Roots, Tubers, Plantains and Bananas in Human Nutrition, FAO Food and Nutrition Series No. 24, FAO, Rome, pp. 59–74.

FAO (1993) *Production Year Book*, Vol. **47**.

FOS (2011) Federal Office of Statistics, Nigeria trade summary. Federal Office of Statistics, Lagos. Francis Group, LLC, Boca Raton, FL.

FAO (2012) *FAOSTAT. Food and Agriculture Organization of the United Nations*, Statistical Division, Rome. Accessed 4 February 2015.

FAO (2013) Save and grow: Cassava: A guide to sustainable production intensification, pp. 641–5140.

Frison, C. and Lopez, F. (2011) *Plant Genetic Resources and Food Security Stakeholder: Perspectives on the International Treaty on Plant Genetic Resources for Food and Agriculture* (Eds C. Frison, F. Lopez and J.T. Esquinas-Alcázar), FAO, Rome.

Hamon, P., Dumont, R., Zoundjihekpon, J., Ahoussou, N. and Tio-Touré, B. (2001) *Yams, in* Tropical Plant Breeding (eds A. Charrier, M. Jacquot, S. Hamon and D. Nicolas), SPI and CIRAD, France.

Hertel, T.W. (2010) The Global Supply and Demand for Agricultural Land in 2050: A Perfect Storm in the Making. *GTAP Working Paper No. 63*, Purdue University, West Lafayette, IN.

Hollyer, J.R. and Sato D.M. (1990) Proceedings of Taking Taro into the 1990s: A Taro Conference. *Research Extension Series I*, Hawaii Institute of Tropical Agriculture and Human Resource, University of Hawaii, Manoa.

Howeler, R.H. (2008) Background and general methodology used in the Nippon Foundation project, in: *CIAT 2008: Integrated Cassava – Base Cropping Systems in Asia – Working with Farmers to Enhance Adoption of More Sustainable Production Practices*. Proceedings of the Workshop on the Nippon Foundation *Cassava* Project in Thailand, Vietnam and China held in Thainguyen, Vietnam, pp. 5–32.

http://www.fao.org/wairdocs/tac/x5791e/x5791e0c.htm (2015) Report on the intercentre review of root and tuber crops research in the CGIAR, in: *FAO Corporate Document Directory*. Natural Resources Management and Environment Department, Rome. Accessed 4 February.

http://orissa.gov.in/e-magazine/Orissareview/Aug2006/engpdf/71-72.pdf. (2015) Elephant Foot yam: A commercial crop for Orissa (eds M. Nedunchezhiyan, A. Saurabh and N. Ranasingh). Central Tuber Crops Research Institute, Dumduma, Bhubaneswar. Accessed 25 March.

http://en.wikipedia.org/wiki/Yam_%28vegetable%29. (2015) Yam (vegetable). Wikipedia. Accessed 4 February.

http://en.wikipedia.org/wiki/Cassava (2015) Cassava. Wikipedia. Accessed February.

http://www.encyclopedia.com/topic/sweet_potato.aspx (2003) P. Woodward, Sweet potato, in:.*Encyclopedia of Food and Culture*. Accessed 4 February 2015.

http://www.guyanatimesgy.com/2013/06/01/cassavas-huge-potential/ (2013) Cassava's huge potential. G. Prescott. Accessed 4 February 2015.

http://www.naturalnews.com/039378_cassava_root_tapioca_recipe.html (2013) The amazing cassava root: Vegan tapioca recipe included. E.L. Zielinski. Accessed 4 February 2015.

http://www.fao.org/Ag/magazine/9809/spot3.htm (1998) Tropical starch misses market. Agriculture and Consumer Protection Department, Food and Agriculture Organization of the United Nations. Accessed 4 February 2015.

http://www.fao.org/english/newsroom/news/2002/10541-en.html (2002) Partnership formed to improve cassava, staple food of 600 million people. Food and Agriculture Organization of the United Nations. Accessed 4 February 2015.

http://www.fao.org/docrep/W0073e/w0073e06.htm#P5658_664014 (2015) Human nutrition in the Developing world: Cereals, starchy roots and other mainly carbohydrate foods. Agriculture and Consumer Protection Department, Food and Agriculture Organization of the United Nations. Accessed 4 February.

IICA (2013) Inter-American Institute for Cooperation on Agriculture (2013) Roots and tubers processing in the Caribbean: Status and guidelines. IICA and CARDI, Port of Spain: IICA. 100 p.

Iwe, M.O. and Agiriga, A.N. (2013) Production and evaluation of *Ighu* from selected cassava varieties using a motorized shredder – a response surface analysis. *Food Science and Nutrition*, **1(6)**: 464–473.

Kabeya, M.J., Kabeya, U.C., Bekele, B.D. and Kikuno, H. (2013) Vine cuttings technology in food yam (*Discorea rotundata*) production. *Asian Journal of Plant Science and Research*, **3(3)**: 107–111

Kaushal, P. and Sharma, H.K. (2014) Effect of incorporating Taro (*Colocasia esculenta*), Rice (*Oryza sativa*) and Pigeon Pea (*Cajanus cajan*) flour blends on noodle properties. *International Journal of Food Properties*, **17(4)**: 765–781.

Kaushal, P., Kumar, V. and Sharma, H.K. (2012) Comparative study of physicochemical, functional, anti-nutritional and pasting properties of taro (*Colocasia esculenta*), rice (*Oryza sativa*) flour, pigeon pea (*Cajanus cajan*) flour and their blends. *Lebensm Wiss Technology*, **48(1)**: 59–68.

Kouassi, N.K., Nindjin, C., Tetchi, A.F. and Amani, G.N. (2010) Evaluation of type of process on functional properties and on nutritional and anti-nutritional composition of yams (*Dioscorea cayenensis-rotundata*). *Journal of Food Technology*, **8(4)**: 191–199.

Krieger, H. (2010) *Shelf life determination of Idaho and Red potatoes stored in three types of bags. Research paper submitted to Graduate School University of Wisconsin-Stout*, Menomonie, WI.

Kumar, V., Sharma, H.K, Kaushal, P. and Singh, K. (2015) Optimization of taro–wheat composite flour cake using Taguchi technique. *Journal of Food Measurement and Characterization*, **9(1)**: 35–51.

Kwok, J. (2008) *Cyanide poisoning and cassava, in:* Food Safety Focus*, 19th Issue*. Centre for Food Safety, The Government of Hong Kong.

Lawrence, G. and Walker, P.D. (1976) Pathogenesis of *E. necroticans* in Papua New Guinea. *Lancet*, **2:** 125–126.

Lin, S.S.M. and Chen, D.M. (1985) Sweet potato production and utilization in Asia and the Pacific, in: *Sweet Potato Products: A Natural Resource for the Tropics* (ed. J.C. Bouwkamp), CRC Press, Boca Raton, FL, pp. 139–148.

Mackenzie, D.R. (1995) Progress report on the Inter-centre review of root and tuber crops research in the CGIAR. Agenda item no. 6. TAC Secretariat, Food and Agriculture Organization of the United Nations, Rome.

Montagnac, J.A., Davis, C.R. and Tanumihardjo, S.A. (2008) Processing techniques to reduce toxicity and anti-nutrients of cassava for use as a staple food. *Comprehensive Reviews in Food Science and Food Safety*, **8(1)**: 17–27.

NPARR (2010) Quantitative and qualitative aspects of elephant foot yam. A quarterly electronic repository of current information on natural products and resources, *NPARR*, **1(2)**: 2010–0296.

Obazu, F.O. (2008) Isolation and characterization of cassava linamarase using centrifuge and cross flow membrane. A dissertation submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg.

Ojo, A. and Akande, E.A. (2013) Quality evaluation of "gari" produced from cassava and sweet potato tuber mixes. *African Journal of Biotechnology*, **12(31)**: 4920–4924.

Okoth, P., Okoth, S. and Jefwd, J.M. (2013) The conservation and use of micro-organisms and invertebrates in root crop-based systems: State of knowledge, trends and future prospects. *Background study paper no. 63,* Commission on Genetic Resources for Food and Agriculture, FAO, UN.

Olatoye, K.K., Akinoso, R., Lawal, A.I. and Babalola, K.A. (2014) A comparative study of energy demand of instant-pounded yam flour production methods. *Journal of Energy Technologies and Policy*, **4(3)**: 14–18.

Omoruyi, F.O., Dilworth, L. and Asemota, H.N. (2007) Anti-nutritional factors, zinc, iron and calcium in some Caribbean tuber crops and the effect of boiling or roasting. *Nutrition and Food Science*, **37(1)**: 8–15.

Oyewole, O.B. and Sanni, L.O. (1995) *Constraints in traditional cassava processing: A case of "fufu" production, in:* Transformation Alimentaire Du Manioc (Cassava Food Processing) (eds T.A. Egbe, A. Brauman, D. Griffon and S. Treche), Institut Francais de Recherche Scientifique Pour le Development en Cooperation (ORSTOM), Paris, pp. 523–529.

Palaniswami, M.S. and Peter, K.V. (2008) *Tuber and Root Crops*. New India Publishing House, India, **9**, pp. 1–498.

Patricia, G.O.D., Alistair, P. and Emmanuel, L.O. (2014) Cocoyam (corms and cormels): An under-exploited food and feed resource. *Journal of Agricultural Chemistry and Environment.* **3(1)**: 22–29.

Pena, R.S. de la, and Pardales, J.R. (1984) *Evidence of proteolylic enzyme activity, in:* taro, Colocasia esculenta, Symposium of the International Society Root Crops, International Potato Center, Lima, pp. 157–l59.

Philbrick, D.J., Hill, D.C. and Alexander, J.C. (1977) Physiological and biochemical changes associated with linamarin administration to rats. *Applied Pharmacology*, **42**: 539–551.

Roxas, M.J.T., Fukuba, H. and Mendoza, E.M.T. (1985) The absence of oligosaccharides in storage roots of sweet potato (*Ipomoea batatas* L.). *Philippines Journal of Crop Science*, **10(3)**: 161–163.

Sahore, D., Amani, N. and Kamenan, A. (2006) Anti-nutritional factors in wild yam tubers. *Tropical Science*, **46**: 113–115.

Salyers, A.A., Palmer, J.K. and Wilkins, T.D. (1978) Degradation of polysaccharides by intestinal bacterial enzymes. *American Journal of Clinical Nutrition*, **31**: 128–130.

Senanayake, A., Ranaweera, K.K.D.S., Gunaratne, A. and Bamunuarachchi, A. (2013) Comparative analysis of nutritional quality of five different cultivars of sweet potatoes (*Ipomea batatas* (L) Lam) in Sri Lanka. *Food Science and Nutrition*, **1(4)**: 284–291.

Shajeela, P.S., Mohan, V.R., Jesudas, L. and Tresina Soris, P. (2011) Nutritional and anti-nutritional evaluation of wild yam (*Dioscorea* spp.). *Tropical and Subtropical Agroecosystems*, **14**: 723–730.

Shin, M.Y., Cho, Y.E., Park, C., Sohn, H.Y., Lim, J.H. and Kwun, I.S. (2012) The supplementation of yam powder products can give the nutritional benefits of the antioxidant mineral (Cu, Zn, Mn, Fe and Se) intakes. *Preventive Nutrition and Food Science*, **17(4)**: 299–305.

Slavin, M., Kenworhty, W. and Yu, L. (2011) A single extraction and HPLC-UV ELSD. procedure for quantification of phytosterols, tocopherols and lutien. *Institute of Food Technologist Meeting*, 11–14 June, New Orleans.

Taiwo, K.A. (2006) Utilization potentials of cassava in Nigeria: The domestic and industrial products. *Food Reviews International*, **22**: 29–42.

Troung, V.D., Avula, R.Y., Pecota, K. and Yencho, C.G. (2011) Sweet potatoes, in: *Handbook of Vegetables and Vegetable Processing* (ed. N.K. Sinha), Wiley & Blackwell, New Jersey, pp. 717–737.

Udoro, E.O. (2012) Studies on the processing of gari from dried cassava chips. Unpublished MSc Thesis in Food Science and Technology. Obafemi Awolowo University, Ile-Ife, Nigeria, pp. 60–82.

Valli, C., Balakrishnan, V., Karunakaran, R., Bharathidhasan A., Ramesh, J. *et al*. (2013) A Guide in Animal Nutrition to TNPSC Examination. Department of Animal Nutrition, Madras Veterinary College, Chennai, India.