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Cocoyam (corms and cormels)—An underexploited food and feed resource

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ABSTRACT

Cocoyams (old-taro: *Colocasia esculenta*; new-tannia: *Xanthosoma sagittifolium*) yield corms as root crops produced in regions of tropical and sub-tropical developing countries. In certain countries such as Ghana, there are surpluses in production but deficits in cereals. Cocoyams are used in a range of indigenous foods. Post harvest losses are high due to mechanical damage of corms during harvest and microbial attacks on such damaged corms during storage. Cocoyams contain, on average, 25% starch (wet weight basis) with A-type structures characterized by small granule size (<1.5 μm). Non-starch polysaccharides in cocoyams confer gummy properties to the starch. However, mechanical effects of raphides—crystals of calcium oxalate and other components—produce irritation when raw corm tissue is ingested resulting in several levels of discomfort. With appropriate processing, cocoyams could be a rich source of starch for food and industrial applications and corms have potential for new product development. Stabilizing cocoyam crops and adding value could greatly improve its utilization in cocoyam producing countries.

KEYWORDS

Cocoyams; Starch; Non-Starch Polysaccharides; *Colocasia esculenta*; *Xanthosoma sagittifolium*; Calcium Oxalate

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1. INTRODUCTION

In many developing countries roots and tubers such as cassava (*Manihot esculenta*), sweet potato (*Ipoemea batatas*), yam (*Dioscorea* sp), and cocoyams (*Colocasia esculenta* and *Xanthosoma sagittifolium*,) are important household food security and income crops. They all contain starch and fibre that can provide energy and satiate the consumer. Generally, cocoyams are extremely cultivated in West Africa. They are important food crop for more than 400 million people worldwide. Cocoyams produce corms with about 25% starch on wet weight basis, primarily consumed as purees mixed with other ingredients. Current statistics indicate cocoyam production increased over 5 years in the 1990s from 5.6 million to 8.8 million metric tonnes [1] and in the 1980s produced at 5.5 million metric tonnes, 3.3% of root crops [2]. Global production of taro has been estimated as approximately 60% in Africa and 40% in Asia, with minor quantities in the Caribbean and Oceania, over an area of 983 million hectares, with average yield of 5.314 mt/ha [3]. In Ghana the average yields for cocoyams (tannia and taro) are 6.7 mt/ha and 9.5 mt/ha, far below the potential yields of 8.0 mt/ha and 12.0 mt/ha respectively. The mean annual production growth rate of tannia has dropped by 3.4% and the per capita consumption declined from 56 kg/head/yr. in 2000 to 40.0 kg/hd/yr. in 2005 [4]. Exports of cocoyam have increased by over 23% in volume, but have been static in value.

2. AROID TAXONOMY

The cocoyams are aroids, grown primarily for edible corms, belonging to the family *Araceae*, which has 110 genera—of which *Colocasia*, *Xanthosoma*, *Amorphallus*, *Alocasia* and *Cytosperma* are important—and about

2000 species. *Alocasia*, *Xanthosoma* and *Colocasia* belong to the tribe *Colocasia* is in the sub-tribe *Colocasinae*; *Xanthosoma* in the sub-tribe *Caladinae*. The family *Araceae* is grown in a number of tropical and sub-tropical countries and has been identified as a major group of underexploited root crops with an uncertain future through limited demand that may lead to reduced production until it becomes a minor niche crop [5].

The terms "edible aroids" or "cocoyams" are used for both *Colocasia* and *Xanthosoma*, referred to as taro and tannia, respectively, when differentiated in post-harvest characteristics. Other edible aroids, of lesser economic importance, include *Alocasia*, *Cyrtosperma* and *Amorphophallus*, cultivated locally to form important food crops in parts of India, Southeast Asia, and Pacific Islands [5-7]. Cocoyams are less important than other tropical root crops such as yam, cassava and sweet potato but form subsistence and emergency crops in many countries and are a stable crop in parts of Ghana, Japan, Nigeria and Hawaii. In South Pacific Island countries, edible aroids, principally taro, form a high proportion of the root crops however in the Caribbean and West Africa, tannia dominates [8].

Tannia is a crop of South (tropical) American origin domesticated by the tropical Amerindians and people of the Caribbean and is called malanga in Cuba and yautia in the Dominican Republic and Puerto Rico. During the slave trade it was taken to Africa and since the nineteenth century it has been cultivated in Pacific islands and Asia because of its resistance to pests and diseases. Other names include mankani, tanier, belembe, maduma, yautia de Anglo-saxon, macabo, gualusa, tannie, chou caraibe and mangarito [5,7].

Taro (*Colocasia esculenta*) or taro eddoe, dasheen gabi, keladi, taru, arvi, kolkas, dalo or sato-imo has been the focus of cocoyam research and its agronomic and phenotypic properties have been more studied.

3. CHARACTERIZATION OF COCOYAMS

Cocoyams are characterized morphologically by subterranean stems, corms, enclosed by dry scale-like leaves. The cocoyams are differentiated in leaf attachment: tannia has the stalk attached to the leaf edge whereas in taro it emerges near the centre. In tannia secondary corms (cormels) are used for human consumption while the corms are used for vegetative propagation. Taro is a versatile crop grown in both lowland and upland conditions whereas tannia cannot stand water-logging and is a partial shade-loving annual crop that prefers deep well drained soils of pH 5.5 - 6.5 and tolerates saline soils [5].

Biophysical and socio-economic factors accounting for the lower yields include low yielding cultivars, pest and disease, poor husbandry practices, deteriorating soil fertility, lack of processing and innovation of products. Cocoyams are susceptible to attack by pests and diseases. A typical pest is the slugs that wound corms, providing entry points for spoilage micro-organisms. Losses can reach 60% of corms. Prevention is by use of disease free planting material, weeding and hilling and treatment with copper-based pesticides [8]. **Figure 1** shows pictures of freshly harvested cocoyams.

4. POST HARVEST ISSUES

Corms can start rotting as early as two weeks after harvest, with tannia suffering less than taro, and Passam (1982) [9] recorded 90% losses in six months of storage. Such microbial decay can be controlled by pre-storage fungicide and sodium hypochlorite applications as dips, normally within 24 h after harvest. Damage to cocoyam tissue is followed by enzymatic browning reactions from polyphenol oxidases catalyzing the oxidation of polyphenols resulting complex formation leading to the production of pigments that cause discolourations. Sprouting and chill injury at low storage temperature also reduce quality in stored corms [8].

Despite local economic importance, there is limited scientific information on post-harvest properties and related commercial food applications. This has limited application of post-harvest technologies to maintain quality and improve marketing potential [10]. Cocoyam production

Figure 1. Freshly harvested cocoyam.

could benefit from application of technologies that could limit rot losses and improve marketing, enhance nutritional value, and add economic value through the food chain.

5. COCOYAM COMPOSITION

Tagodoe and Nip (1994) [11] concluded taro flours are rich in starch and total dietary fibre and low in fat, protein and ash. Moisture contents are 69.1% and 67.1% respectively for taro and tannia: energy values—4800 and 5210 KJ/kg; fat contents 0.10% and 0.11%; sugar contents 1.01% and 0.42%; ash contents 0.97% and 1.01% [12].

Taro corms contain pigment anthocyanins such as cyanidin-3-glucoside, pelargonidin-3-glucoside and cyanidin-3-rhamnoside; and anthocyanogens [13].

5.1. Cocoyam Starch

Cocoyams contain 20% - 28% starch: taro 24.5%; and tannia 27.6% [14]. Tannia starch granules under the light microscope are oval to kidney shaped with the smaller granules appearing spherical [15] although Gunaratne and Hoover (2002) [16] reported polygonal to variable shapes and taro starch granules are 5 - 6 sided polygons [15]. On the basis of scanning electron microscopy (SEM) data, Lawal (2004) [17] concluded tannia granules were polygonal. Granules appear larger in tannia starch (0.74 - 1.19 µm) than in taro (0.08 - 0.25 µm). Cocoyam starch granule dimensions are thus smaller than those of cassava (*Manihot esculenta*) and other root crops such as true yam (*Dioscorea alata*), and potato (*Solanum tuberosum*) [15,16,18,19]. The smaller starch granules of cocoyam have been associated with increased digestibility over other starchy crops [20]. The starch molecules are round and polygonal in shape [17,21]. The granule sizes vary from 15 - 40 µm. It has been reported that starch yield ranges from 30% to 88% [17,22].

From X-ray diffraction data tannia starch is A-type, typical of cereal starches [17,23-26] whereas most tuber starches show B or C patterns. When 10% starch suspension is heated, amylograph studies have revealed starches of both red and white tannia and taro show good thermal and storage stability [15]. A low paste (gelatinization) temperature, relatively high cold paste viscosity and high water and oil absorption capacities make cocoyam flours good binding agents capable of reducing food and cooking losses and conserving flavour and body in food products [27]. There is thus a potential for these functional attributes in new product development.

Low pasting temperature reduces energy input in food systems where thickening or gelling is required. Of five starches—true yam, *Alocosia* sp., cassava, tannia and potato—Guanratne and Hoover (2002) [16] reported tannia was the least susceptible to the action of acid (2.2 M HCl) at 35˚C and most susceptible to hydrolysis by porcine amylase.

5.2. Non Starch Polysaccharides

Nutritional and functional properties of taro and tannia corm tissues can be modified by contributions from non-starch polysaccharides. Ramsden & Ling (1998) [28] reported several fractions in taro, the most abundant identified as the water-soluble arabinogalactan proteoglycan. This is the main polymer present in the water soluble mucilage present in taro corms [29].

Whole flour monosaccharide analyses revealed xylose and mannose contents indicative of xyloglucan and glucomannans [28] with unknown influences on functional properties. High arabinogalactan contents contribute a mucilaginous character to taro corms pastes. Dietary fibre contents have been reported as 1.46% for taro and 0.99% for tannia [12].

5.3. Cocoyam Proteins

Cocoyams have, at 1.12% for taro and 1.55% for tannia, higher protein contents than most other tropical root crops [30]. Protein quality appears similar for all aroids determined, with lysine as first limiting amino acid (chemical score 57 - 70) [14].

Two major globulins from corms of taro have been characterized by de Castro *et al.* (1992) [31] and Monte Neschich *et al*. (1995) [32]. They observed the presence of two unrelated globulin families during tuber development—a G2 protein with both storage and trypsin inhibitor activity and a G1 protein, tarin, also with storage, defensive and protein inhibitor activity. They account for up to about 80% of total soluble tuber proteins.

The G2 proteins, accounting for 40% of soluble corm proteins have been reported to have molecular weights of 24,000 and 22,000 daltons and pIs close to 7.5. It appears these proteins have a storage role and trypsin inhibitor activity.

The trypsin inhibitor is thought to belong to the Kunitz family of protease inhibitors [33] which includes sweet potato storage protein, sporamin. The sequence of amino acids of the storage protein has also been reported to be similar to the taste-modifying protein, miraculin, which is extracted from the miracle berry plant, *Richardella dulcifera* [31,34].

Tarin has been reported to account for about 40% of total soluble corm proteins and consists of about 10 isoforms. They have pIs ranging from 5.5 to 9.5. Their weight has been reported to be about 28,000 daltons. Tarins have quite a similar sequence homology to mannose-binding lectins found in snowdrop, *Galanthus nivalis*, and wild arum, *Arum maculatum* [35-38]. Such mannose-binding lectins have been reported to agglutinate erythrocytes of rabbits but not of humans [39]. The nature of tarins in cocoyams gives them a defensive role as well as storage.

Some tarins have been reported to have an amino acid sequence similar to curculin, a taste modifying protein from the fruits of *Curculago latifolia* [40]. The similarity in the sequence of the G2 proteins and tarin to miraculin and curculin, respectively, is of interest to researchers in investigating the taste modifying properties of cocoyam storage proteins.

Taro corm polyphenol oxidases have been characterized with respect to molecular weight, pH and temperature optima, inhibitor effectiveness and relative substrate specificities [41].

5.4. Cocoyam Antinutrient Components

Food and feed usage of cocoyam is restricted because of the acrid nature of the corms that irritate upon ingestion and lowers palatability [42]. This has reduced possibilities for processing. The acridity is such that if eaten raw, corms cause swelling of the lips, mouth and throat as well as bitterness, astringent taste and scratchiness in the mouth and throat. Antinutritional and off-taste problems have been related to content of needle-like raphides of calcium oxalate crystals and other acidic and proteinacious factors [12,43-47]. Bradbury & Nixon (1998) [43] have explained the acridity as due to the mechanical the sharp raphides in puncturing the soft skin and irritant proteases and other compounds [48]. Paull *et al*. (1999) [45] have proposed the presence of one or more chemical irritants on raphide surfaces. Content of calcium oxalate raphides has been reported to decrease from outer to the centre of the corm [49] and be more abundant in distal sections than mid- or apical [15]. Effects of cocoyam antinutritional factors range from reductions of food and feed intake, with depression of weight gain, to pancreatic hypertrophy in experimental animals [50-55].

Other specific antinutritional factors have been reported such as trypsin inhibitors [56,57], α-amylase inhibitors [58] and sapotoxins [59].

Philipy *et al*. (2003) [60] concluded levels of phytate in taro at 0.169% were higher than cassava (0.133%). Bradbury *et al*. (1995) [61] reported contents of cyanide present in the leaves (0 - 30 mg HCN Kg^{-1} fresh weight) and in the stems (0 - 3 mg HCN Kg^{-1}) of taro and tannia were only about 1% - 5% that of cassava leaves and tubers and are thus not a cause for concern for human nutrition.

6. PROCESSING EFFECTS ON QUALITY

Njintang and Mbofung (2003) [62] prepared flour suitable for achu and other foods and observed drying temperatures influenced colour and flour gelatinisation. Corm conversion tubers flour reduces water content and this could contribute markedly to resolving post-harvest storage problems. Hong and Nip (1990) [63] have reviewed literature on conversion of taro into flour. In the Pacific areas, precooked taro flour is traditionally prepared by boiling tubers to a soft texture followed by drying and grinding. Cocoyam processing is aimed at generating products stable in terms of shelf-life, nutrition and palatability.

Antinutrient calcium oxalate content of corms has been reported decreased by peeling and boiling [53] and trypsin inhibitor content in taro tubers by oven (thermal and microwave) drying [38], most effectively by microwave baking.

Rekha and Padmaja (2002) [64] studied amylase inhibitor activity in processed taro and observed α-amylase inhibitors were almost totally inactivated with oven drying of the chips at 90˚C and 100˚C for 24 h. Boiling taro chips in water yielded between 84% and 89% reductions in α-amylase inhibitor activity and higher values for microwave baking. Prathibha *et al*. (1998) [65] concluded processing methods like frying, boiling, baking and pressure cooking leading through heat inactivation to significant losses in activity of α-amylase, trypsin and chymotrypsin-inhibitor activities of cocoyams and concluded frying was the most effective method of eliminating enzyme inhibitors.

Gunaratne and Hoover (2002) [16] reported isolated tannia and taro starch subjected to heat under controlled moisture conditions. It has been reported that cooking of taro corms results in cell wall changes with early solubilization of pectic polysaccharide and changes in xyloglucan extractability [66].

7. USES OF COCOYAMS

Cocoyam usage can be similar to that of potato in the western world and corms can be converted into several specific food and feed products and also for industrial purposes. Processes for stabilizing and adding value by conversion to semi-finished and end products include boiling, roasting, baking, frying in oil, pasting, milling and pounding. Arnaud-Vinas and Lorenz (1999) [67] have also considered the possibility of production of pasta from blends of wheat and taro flours.

A typical common product is the Ghanaian fufu—a pounded mass of boiled cocoyam. It is also used in soup thickeners and baking flours, in beverages, as porridge and in producing foods for people with gastrointestinal disorders [44,68-70].

Subhadhirasakul *et al.* (2001) [71] reported that taro starch can effectively replace maize as a binding agent in tablet manufacture. Lawal (2004) [17] has suggested cocoyam starches could be modified as for other industrial starches.

The high digestibility of cocoyam starches and the small size of taro granules form a good basis for processed baby foods. In parts of West Africa, boiled corms are mashed to form a weaning diet. Onwulata and Konstance (2002) [72] have reported on the process of formulation of weaning food with taro flour extruded with whey protein concentrate, whey protein isolate and lactalbumin.

Mature aroids are processed into flour for fufu, commonly eaten in Nigeria with stew. In south eastern parts of Nigeria in particular, tannia is used in small quantities as a soup thickener after boiling and pounding to obtain a consistent paste [69,70].

Taro chips are an important product and young taro leaves are an excellent vegetable and in the South Pacific, incorporated with coconut cream to prepare a dish called “luau”, which consumed with boiled or roasted taro, breadfruit and banana [8]. Roasted or boiled corms can also be eaten alone or with stew.

Taro flours have unique properties from small starch granules (<1.5 μm) and high mucilage (gum) content, suggesting a replacement for corn or wheat starch in weaning foods. When whey was blended with taro flour extrudates expanded more and were easier to grind into powders; and more readily rehydrated. Taro extrudates without protein absorbed more water, and were more soluble. Extrusion cooking and whey protein addition significantly reduced gummy properties of mucilage in flours [72].

The use of cocoyam as a raw material for brewing has been reported by Onwuka and Enneh (1996) [73]. The final beer, though slightly bitter, was acceptable to local assessors.

Ethnic Cocoyam Products

Poi is a purplish paste of cooked taro produced in Hawaii [63]. It undergoes natural fermentation or is eaten unfermented. Occasionally, sugar and milk are added before consumption.

Achu, a meal made from pre-gelled taro flour, in a process studied by Njintang and Mbofung (2003) [62] is traditionally prepared by a combination of peeling, boiling, pounding and mashing in a mortar to obtain a paste. Achu is a valued food product in Cameroon [62].

Sapal is a fermented meal prepared with taro corms and coconut cream in a process described by Gubag *et al*., 1996 [74].

8. THE FUTURE OF THE COCOYAM INDUSTRY

The future of the cocoyam industry depends on selection of high yielding, quality genotypes and development of low cost technologies that will enhance its production [75]. For edible aroids to play a sustainable significant role in contributing to food security in producing countries there is the need to broaden the genetic base of the crop through modern biotechnologies and through the exchange of germplasm and information between producing countries. Traits of interest to be included in the selection of improved varieties should include high yielding, drought tolerant, early maturing, pest and disease resistant/tolerant, improved post harvest and good culinary characteristics. The development of three high yielding, Root Rot and Leaf Blight tolerant varieties of cocoyam (tannia) in Ghana will mitigate the declining productivity of the crop. In collaboration with the International Network of Edible Aroids efforts are underway in Ghana to develop Leaf Blight tolerant varieties of taro. The Taro Leaf Blight has almost devastated the Taro industry in Ghana and the sub-region.

Planting material acquisition is a big challenge to cocoyam farmers due to the inherent low multiplication ratio of the corms. There is therefore the need to research and train farmers on cheap and simple ways of generating planting materials. In Ghana the mini sett technique used in yam multiplication has been experimented and has proved successful in multiplying cocoyam (tannia) during Farmer Field Forum sessions in some parts of the country.

The need to improve production on sustainable basis is crucial in the aroid industry. Evolving crop management systems using low input technologies, biofertilizers, and water management etc. will critically address issues on sustainability and stability in edible aroid production. The system in which animal manure is use to complement fertilizer needs in an intensive production system as suggested by Wang and Nagarajan, 1984 [76] and could be adopted by farmers to avoid depending on nutrients supplied on newly cleared forest lands which have become scarce. Continuous research activities with farmers as close collaborators will enhance adoption of other related agronomic technologies generated by Scientists and boost production.

Industrial uses of cocoyam in the production of flour, baby foods, starch and non-starch products, biodegradables and other novel products as examined by Griffin, 1979 [77] if pursued, sustained and expanded will mitigate post harvest lose, boost cocoyam production in producing countries and enhance food security.

9. CONCLUSIONS

Aroids are high in starch content and low in protein and lipid with a considerable potential as animal feed, renewable energy source and industrial raw material but the potential of cocoyams remains to be realized in the development of agro-industries. It remains a staple of areas in many developing countries where post-harvest losses cause economic and agronomic problems.

From research, taro flour is unique because of a very small particle size (<1.5 μm) and high mucilage or gum content, making it a possible replacement for corn or wheat starch. The consumption of other cereal staples (rice, maize, sorghum and millet) in developing countries like Ghana exceeds national production and necessitates imports. In contrast, for the cocoyams, the other root crops (yam, cassava) and plantain, there are recorded surpluses and significant wastage.

Considering the high polysaccharide content, together with abundance in the tropics, cocoyam corms could be considered as a raw material for the food and biotechnical industries in these regions. Research and new product development would allow development of the potential of cocoyam corm starches. Priorities in research should be characterizing cocoyam starch and non starch polysaccharides and their properties and further modification and manipulation. Economic processes for stabilizing corms and cocoyam flours and the ability to reduce post-harvest losses and addition of value could resolve the food security problems in cocoyam producing areas.

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