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Unveiling Cocoyam Potentials: Physiology and Agronomy

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Abstract
Cocoyam is one of the world's oldest food crops grown purposely for food. Though, commonly produced by smallholder, resource-limited and mostly female farmers, it plays important roles in nutrition, food security and agrobiodiversity in Africa. However, it has been identified as an underutilized crop that may suffer genetic erosion and an uncertain future due to limited research interest and demand. This study aims to provide more insight on the physiology of cocoyam, to aid innovative technologies and agronomic practices that will increase its productivity and production efficiency. The information and data used were collected from sources such as Google Scholar, Science Direct, Research Gate, FAOSTAT and research activity reports of the National Root Crops Research Institute, Umudike, Nigeria. Though the cocoyam production area in Nigeria has increased, yield per unit land area decreased from 6.6 in 2000 to 4 t ha^{-1} in 2020. Growing cocoyam and optimizing the yield sustainably will boost food and nutrition security, protect biodiversity and reduce climate risks. The study suggests that an in-depth understanding of the crop's physiology, growth stages and characteristics will inform better agronomic practices and guide technological breakthroughs that will increase yield and value, thereby reinstituting its relevance in the food system and the environment.

Keywords: Cocoyam physiology, taro, tannia, food security, climate risks, agrobiodiversity

Introduction

Taro (*Colocasia esculenta)* and tannia (*Xanthosoma sagittifolium*) are important root crops grown in the tropics and sub-tropics purposely for food security. They are examples of the world's oldest food crops believed to have been first domesticated in Southeast Asia before their eventual spread to other parts of the world (Ubalua *et al*., 2016). Taro is majorly grown in East Africa and South Pacific Island countries, while tannia dominates in the Caribbean and West Africa (Lebot, 2009). In general, Africa cultivates more of tannia (*Xanthosoma)* and it is replacing taro (*Colocasia)* because the local cultivars seem more adapted to the preparation of *fufu* and resilient to drought stress. However, taro is versatile and can be grown in both lowland and upland conditions (Lebot, 2009; Onwusu-Darko *et al*., 2014). Recently, the disturbing threats to food security in sub-Saharan Africa (SSA) resulting from factors such as, increasing population, climate change, and low productivity of edible crops call for the identification of potential alternative sources to improve food availability. Soil water logging/flooding is on the increase, adversely affecting crops like cassava. Taro is highly tolerant to flooding and grows without problems in waterlogged situations, with many other advantages, such as increased yields due to the activation of photosynthesis and reduced application of herbicides and insecticides (Yamanouchi *et al*., 2022). For this study, the term cocoyam is used for both taro and tannia, following (Lebot, 2009; Owusu-Darko *et al*., 2014). In many parts of Asia and the Pacific, the term cocoyam or "edible aroids" are used to refer to taro and tannia. Cocoyam has been identified as a major group of underexploited root crops that may suffer genetic erosion and uncertain future due to limited research interest and demand, which has led to reduced production of the crop. Among other root and tuber crops such as cassava, yam, sweet potato and potatoes, cocoyams are treated as less important (Chukwu *et al*., 2017) and underutilized in the areas of human consumption, agro-industrial raw material for pharmaceutical, confectionery, livestock industry and medicinal uses in Africa (Otekunrin *et al*., 2021). Nevertheless, it plays important roles in nutrition, food security, agrobiodiversity and rural development.

Cocoyams contain more than twice as much carbohydrate as potatoes and about 11% protein on a dry weight basis, with the protein content higher than most other root crops in leaves, tubers and storage roots

(Bhagyashree *et al*., 2011). The high dietary fibre content in cocoyam is beneficial due to its active role in regulating intestinal metabolism. In most cases, the prevalence of malnutrition in the rural population could be attributed to food choices - neglecting food crops like cocoyam which contains sufficient nutritional resources to meet their daily needs. For instance, zinc deficiency is common, affecting the health and well-being of especially rural dwellers who have limited access to variable food types or vitamin supplements. Cocoyam is one of the few sources of non-animal zinc that help alleviate zinc deficiency and its effects (Lebot and Legendre, 2015). However, there are anti-nutritional components that discourage the consumption and use of cocoyam. They include tannins, cyanides and oxalic acid. Oxalic acid is responsible for the pungent taste and the irritation experienced when a half-cooked or raw one is consumed (Njintang *et al*., 2008). This causes much discomfort and high consumption of it is detrimental to health. The advantage is that these anti-nutrients are destroyed by heat through boiling, roasting or baking until well cooked.

Globally, cocoyam production is increasing at a snail's speed from 9. 8 million tons in 2000 to 12.8 million tons in 2020 (Knoema, 2022; FAOSTAT, 2022), when compared with that of other root crops, especially cassava and sweet potato. Nigeria is the leading global producer of cocoyam with an average of about 3.7 million metric tonnes between 2000 and 2020, taking up about 27 % of global production (FAOSTAT, 2022). In Nigeria, a large amount of cocoyam produced is consumed as food, either as a primary product (corm, cormel and leaves) or as a secondary product (flour, cake, crisp, and chip). Cocoyam is the only fully edible tuber crop because the corms and cormels are eaten in various food forms, the leaves are rich sources of protein and the flowers are commonly used as spice. Cocoyam is nutritionally superior to cassava and yam, in terms of digestibility, crude protein contents and essential minerals (Otekunrin *et al*., 2021). It is majorly cultivated in humid zones, particularly in the rainforest, rainforest transition and guinea savanna agroecological zones. Usually grown by resource-limited and mostly female smallholder farmers managing small plots of less than two hectares (Onyeka, 2014). In Nigeria, the area harvested of cocoyam has stagnated for over two decades now and yield per unit land area (Fig. 1) decreased within the period, from 6.6 in 2000 to 4 t ha^{-1} in 2020 (FAOSTAT, 2022). Undoubtedly, the production trend (Fig. 1) depicts neglect of the crop and poor crop management. The decline in production has resulted in a shortage of supply in domestic markets and is hampering other opportunities such as new food form discoveries, industrial uses and foreign trade. It is assumed that most families no longer consume it due to its rarity in the market. On the other hand, it appears that consumers prefer other food crops to cocoyam (Abdulrahman *et al*., 2015). Also, the stagnating productivity could be linked to the continued neglect of the crop by research scientists. To date, there are no improved varieties of cocoyam in Nigeria that is resilient to root rot, leaf blight, or other diseases and pest. A better option is the sustainable intensification of the cocoyam cropping system which will positively impact the crop's productivity.

The need to refocus on improving cocoyam's productivity and value chain has become inevitable due to the growing need to address food and nutrition insecurity in the continent. A renewed commitment towards the crop's improvement alongside awareness creation of its benefits could regenerate the crop. Recently, cocoyam is gaining attention from policymakers, NGOs, national and international agricultural research institutions due to concern over biodiversity. Efforts should be intensified towards achieving the conservation and increasing cultivation of diverse crops to deliver foodstuffs needed for food and nutrition security, conserve biodiversity and mitigate climate change impacts (Rudebjer *et al*., 2009). Developing improved cocoyam varieties and intensifying the production need basic information about the crop's physiology, supported by location-specific agronomic practices. In this review, we aimed to understand the growth and development pattern of cocoyam under the rainfed production system in Nigeria, including the nutrient requirement and management for improved agronomic practices.

Methodology

This review relied mostly on secondary data available from the Food and Agriculture Organization of the United Nations Corporate Statistical Database (FAOSTAT, 2022) and Knoema.com (an online resource for comprehensive source of decision-making data on crops). Other sources include Google Scholar, Science Direct, Research Gate, FAOSTAT, Wikipedia, journals and national research reports.

The botany and physiology of cocoyam

A common characteristic of all aroids (cocoyam) species is the spathe and spadix type of inflorescence (Fig. 2). The spathe is a bract subtending and unsheathing inflorescence, while the spadix is a spike of flowers on a swollen, fleshy axis. The spadix often ends with an appendix composed of sterile flowers. The main purpose of the appendix is to disperse odorous substances. Cocoyam is characterized by protogyny in which the female flowers become receptive before pollen is shed. Protogyny induces cross-pollination and most of the inflorescences are adapted specifically to insect pollination. Inflorescences in cocoyam are characterized by a specific shape and size of the spathe. The space between the spathe and the spadix serves as a mating place or feeding to support growth and shelter for insects during rain or at night.

The commencement of flowering in the inflorescence of cocoyam is characterized by the release of an attractive fragrance which attracts certain insects. The leaf structure and shapes vary and are adapted to their growing environments such as shade, continuous flooding or drought. The leaf size varies by species and variety and ranges from very small to massive. Extremely large leaves are characteristic of some genotypes adapted in swampy areas. The inflorescences of all cocoyam genotypes, except *tannia*, are appendaged. The appendix on *tannia* inflorescences either is absent or cannot be distinguished clearly. Leaf shape is a useful characteristic for determining genera. The majority of taro (*Colocasia)* species have peltate leaves, while most tannia (*Xanthosoma)* species have sagittate leaves (Lebot, 2009).

The cocoyam, taro and tannia have a similar growth cycle, with six major growth and development phases namely; root formation, shoot development, corm size enlargement, dry matter accumulation in the vegetative parts, dry matter accumulation in corm and cormel and dormancy. During the first 8 weeks after planting (WAP), the growth is slow, it starts with the sprouting of shoots and ends when the cormels emerge. Immediately the sucker or stolon is planted, between 2 and 6 days after planting (DAP) depending on soil moisture availability, the propagule starts to produce new roots. At this stage, the plant utilizes the water and nutrient reserves within the propagule to develop its roots. The rate of root development and its ability to provide support and take up water and nutrients for the growth of the young plant depends greatly on the viability and weight of the propagule. The second phase (10 WAP) is characterized by rapid root and shoot development, with corm initiation. The propagule produces new leaves which allows the growing plant to develop a canopy comprising about five leaves capable enough for light interception. This is followed by maximum root and shot development with a rapid increase in corm size, from 10 to 20 WAP. The plant begins to produce a shallow root system of about 1 to 2 m long around it, as well as new leaves to replace the senescing ones. The number of leaves per main stem of cocoyam genotypes hardly varies, maintaining five to six leaves, depending on the senescing of the oldest leaf and replacement by the younger broad leaf. Phase four begins with rapid dry matter accumulation in the vegetative part aboveground and this takes place between 20 to 30 WAP. During this phase, the plant achieves the maximum leaf area, pseudostem diameter and height (Reyes, 2006). The plant attains its peak in height within the period with significant accumulation of dry matter in the leaves, depicted by thicker and stiffer leaves. From about 25 WAP, the leaves begin to senescence and the total dry weight of the shoot decreases until harvest. Cormel DM accumulation continues after the LAI has reached a maximum at 28 WAP (Lebot, 2009). Cormel bulking during the period of LAI decline occurs because older senescing leaves contribute assimilates to the corm and cormels and because the products of current photosynthesis are being translocated to new leaves as well as to corm and cormels. Cocoyam corm competes for assimilates with cormels, but, the reduction in leaf area reduces corm growth while benefiting cormel growth. From 30 WAP onwards, there is a significant increase in DM in the corm and cormels only and the DM content reaches a maximum of 46 % at 36 WAP for early maturing cultivars and at 45 WAP for late maturing. Dormancy sets in about 40 WAP, at this stage, the crop can either be harvested or left to regrow (Lebot, 2009; Reyes, 2006). The dormancy lasts for one or two months depending on environmental conditions and vegetative regrowth will start again. Farmers are advised to replant annually as the quality of the corm and cormels deteriorates when the plant uses its reserves to initiate new vegetative growth (Lebot, 2009).

Photosynthesis and shading

The rate of photosynthesis in cocoyam increases with growth and reaches the peak at 2 weeks after complete leaf expansion. It remains at optimum for approximately 10 days and then declines with senescence (Lebot, 2009). The potential photosynthesis per plant is determined by the plant density, which controls the amount of light intercepted. A study examined the growth characteristics, different physiological parameters, photosynthetic activity and the translocation rate of photoassimilates in local genotypes to determine the possible use of these parameters as selection criteria for different cultivars. There is a positive correlation between photosynthetic activity, translocation efficiency and total yield (Moussa and Salem, 2006). Cocoyam is shade-tolerant and when grown at 30 % of full sunlight has shown increased stomatal and chlorophyll density, thereby increasing photosynthetic efficiency at low levels of light. Also, results of experiments conducted under the artificial shade provided by a canopy of 50 % shade showed that the plant height and leaf area were higher under shaded conditions compared to full sunlight (Lebot, 2009). Total plant biomass also increased by shade. The corm yields are not affected by shade, but the number and weight of plant suckers were increased. Corm percentage DM, which reflects quality, is higher under shade. The fact that total plant biomass is increased by shade indicates greater photosynthetic efficiency. Due to its shade tolerance, cocoyam is frequently grown in intercropping systems with crops such as banana, coffee, coconut, rubber, oil palm and cocoa.

Growing condition and potential yield of cocoyam

Cocoyam is a warm weather crop and largely cultivated in tropical and subtropical zones, between latitudes 30 degrees north and 15 degrees south of the equator. Unlike cassava, there are cocoyam species that are adapted to waterlogged conditions, while some others produce well in well-drained soils, with annual rainfall between 1400 and 2000, well distributed throughout the growing season. It is resilient to stresses, tolerating a certain amount of shade, drought and heavier or drier soils. The crop can be grown in a range of pH of 5.5 to 6.5 and temperatures between 20 to 35 ºC (Reyes, 2006). Temperatures lower than 18 ºC slow the leaf growth, while higher temperatures than 35 ºC increase the foliage, but limit the corm and cormel formation. The general growth is enhanced when the night temperature is between 14 to 29 ºC. Under these conditions, the production of carbohydrates is increased, hence, optimum yield.

Like other crops grown in SSA, the yield potential of cocoyam is seldom realized, mainly because of a lack of knowledge regarding pest and disease control, proper management practices, and physiological determinants that may limit plant growth and development. Potential yield is the yield of a crop cultivar or variety when grown with water and nutrients that are sufficient enough not to limit crop growth and yield and reducing factors such as weeds, diseases, pests and pollutants are effectively controlled (Van Ittersum *et al*., 2013). Potential yield is location specific because of different agroclimatic zones with varying growing conditions such as climate, soil types, etc. Cocoyam potential yield in traditional cropping systems ranges between 60–110 t/ha fresh yield (Lebot, 2009). An average yield of 37 t/ha has been obtained in Palestine, 9.6 t/ha from Madagascar, 25 t/ha from St Lucia, Americas and 7.6 t/ha from Kiribati in Oceania. In Nigeria, yields ranging between 19 - 21 t/ha were obtained at Enugu in southeastern, Nigeria (Anikwe *et al*., 2015). The yield of the cocoyam is correlated to the weight of the propagule planted and its variety. A vegetative growth index (VGI), which takes into consideration the leaf area of the plant, can be used to determine or estimate the crop's yield even before harvest. Varieties with a high VGI at 20 WAP have the potential to produce a high yield when mature at 36–40 WAP (Lebot *et al*., 2006).

Selection of planting materials and planting density

Planting material showing symptoms of disease or pest should be carefully avoided as they are the main cause of crop infections. Planting materials for taro are prepared from the suckers or the top of the main corm. The head-sett, gotten from the top consists of the upper 1–2 cm section of the corm and the first 30 cm of the petiole. For cocoyam, corm-setts weighing 150 – 200 g or suckers weighing between 200 and 400 g, are ideal for direct field planting. The heterogeneity of the planting materials (suckers, stolons or head-setts) results in highly variable growth and yield of the resulting individual plants, hence planting material should be sorted before cultivation. Head-setts (300–700 g) are more tolerant to drought and yield optimally in good growing conditions. There are also variations between plants within the same genotype, even if the propagules are sorted properly. Studies have shown that planting can be done when propagules start to sprout. Also, the sprouting rate is low in corms planted just after harvesting or after storage at 25°C for 60 days (Lebot, 2009).

Improving the planting density i.e., the number of plants per unit area, can result in an overall yield increase. However, genotypes differ significantly in tolerance to high density and the majority of traditional cultivars are adapted to intermediate densities (0.8 x 0.8 m, 0.7 x 0.8 m, 0.5 x 1.0 m). In Cuba, the planting distance for tannia is 0.9 x 0.35 – 0.4 m, and 0.9 × 0.3 – 0.4 m for taro, depending on seed types, and planting depth should always be 20 – 25 cm. In Nigeria, planting spacing for cocoyam ranges from 1 x 1 m, 1 x 0.5 m to 0.75 x 0.5 m, depending on the purpose, either for crossing block, ware tuber or seed production, respectively (Amadi *et al*., 2012; Udounang *et al*., 2022). Increasing planting density to about 0.3 x 0.3 m is unfavourable to most genotypes. The leaves die earlier, and the plants are left with fewer leaves which are frequently affected by leaf diseases. In fact, the closer the spacing, the smaller the corms. In traditional cropping systems, spacing is usually wider and plants are intercropped. The average corm yield is also higher (4 – 6 kg/plant). In Hawaii, cocoyam spacing ranges between 0.45 x 0.45 m to as wide as 1 x 1 m (10,000 plants/ha). However, wide spacing without intercropping encourages serious competition with weeds and is expensive to control. The mean corm weight is reduced at all planting densities above 10,000 plants/ha. The proper plant spacing for a particular farm does not depend on the final yield only but also on other factors, such as the uniformity of individual corm size to meet various market demands, the weed maintenance programme, the number of propagules the farmer can afford to prepare and, finally, the time of year the farm is planted. Optimal density depends also on the phenotypic characteristics of genotypes. Density-tolerant plants have erect leaves with smaller laminas set vertically and supported by long and erect petioles (Gendua *et al*., 2001).

Nutrient management and cropping system

Cocoyam is considered to be a heavy feeder and exhibits chlorosis when nutrients are deficient. It is sensitive to mineral deficiencies and responds well to applied nutrients. Experiments on the assessment of the nutrient requirements of cocoyam have shown that when plants are fertilized with 100 kg N/ha, 50 kg P/ha and 100 kg K/ha, produced twice the unfertilized. Root biomass develops within 120 DAP but does not increase thereafter (Table 1). The crop takes up more nutrients during phase three of its growth cycle (around 18 WAP), when the plant needs to produce a vigorous root system. The yield depends on its ability to develop its whole root system during this critical period (Lebot, 2009).

In Sri Lanka, the response of *tannia* to various K rates and times of application showed that K deficiency delayed cormel initiation. Further, high levels of available K enhanced the translocation of photosynthates during the growth stage, thereby increasing the availability of carbohydrates for cormel initiation. The number of cormels per plant also increased with increasing levels of K (Sangakkara, 1990) (Table 2).

Though cocoyam prefers well-drained soil, taro also thrives in waterlogged areas. Upland taro and tannia can also be cultivated in sloppy marginal soils when rainfall is sufficient. Good soil management is the basis for obtaining high yields in cocoyam cultivation. Planting may be conducted in the furrow bottom or on ridges. in Cuba, the following fertilizer rates for tannia and taro clones are recommended (Table 3). Split nitrogen rates in four applications for taro, and two applications of K_2O and P_2O_5 are very important for adequate nutrient uptake. In the case of tannia, two-thirds of the total is applied prior to planting and the remaining fertilizer is applied 80 days after planting. Alternative sources of nutrition have been important for cocoyam. Organic matter can be applied at the rate of 20 – 30 t/ha depending on the quality of the organic material (Morales *et al*., 2010).

The yield of cocoyam varies from place to place, depending on the cultivation methods and the environmental conditions. A study in Nicaragua examined the effects of fertilizer on yield when 680 kg of N-P-K 12-30-10 were made at the rate of 170 kg at planting, 40, 80 and 120 DAP. Yield ranged between 2.7 and 10.4 t/ha across locations and genotypes (ReyesCastro *et al*., 2005). A study in southwestern Nigeria showed that application of biochar made from hardwood such as *Parkis biglosa* and *Khaya senegalensis* at the rates of 0, 10, 20, and 30 t/ha and poultry manure at 0 and 7.5 t/ha, either alone or in combination improved plant nutritional status, growth, corm and cormel yields of cocoyam. The combination of 30 t/ha of biochar and 7.5 t/ha of poultry manure improved soil fertility and gave the highest corm and cormel yields of cocoyam at 8 and 10 t/ha, respectively (Agbede *et al*., 2020).

A study at Uyo, Nigeria examined different nutrient applications and intercropping treatments, where NPK fertilizers rates at 0, 200, 400 kg/ha, poultry manure (PM) at 2.5 and 5.0 t/ha, mixture (NPK200 kg/ha + PM2.5 t/ha) and six crop mixtures - sole cocoyam, sole melon, sole maize, cocoyam + maize, cocoyam + melon and cocoyam + melon + maize). Results showed that PM5.0 t/ha and NPK400 kg/ha gave higher values of corm and cormels yield (Udounang *et al*., 2022). Cocoyam intercropping is a common practice especially among smallholder farmers and in traditional agroforestry cropping systems. In Hawaii, yields at harvest showed that under good management, intercropping does not adversely affect the yields of most varieties (Table 4). These yields ranged between 37 t/ha for the control to more than 50 t/ha with groundnut intercrop. In Nigeria, intercropping of cocoyam and rice thrived well in similar ecologies, increasing land use efficiency. It has been shown that growing rice with taro as an intercrop is more profitable than rice or taro alone. The recommended planting arrangement is two rows of cocoyam at 60 x 60 cm spacing, alternating with four rows of rice. Crop management practices such as weeding, fertilizer application and water management remain the same as for sole crop management (Lebot, 2009).

Like cassava, weed control during the first few months of growth, until adequate leaf area index is achieved or leaf canopy cover, reduces competition for moisture, light and nutrients. In smallholder farms, hand weeding is done every 2–3 months and represents the only input during the whole growth cycle (8–10 months). In commercial cultivation, cocoyam is planted in lines and the early establishment of leaf canopy cover is attained by applications of manure, fertilizers and irrigation. Where possible, weeding at 30, 60, 90 and 120 DAP produces higher yields than weeding sparingly at 60 and 120 DAP. In flooded systems where taro is cultivated, the water surface contributes efficiently to the maintenance of weed-free ponds in addition to many other benefits (Yamanouchi *et al*., 2022). Herbicides are also very efficient in controlling weeds. However, taro is, in fact, very sensitive to glyphosate, which can cause interveinal chlorosis and distortion of the emerging leaves. A high dosage causes 'shoestringing' in the emerging leaves and finally kills the plant. Drift control by spraying with thickening agents during windless early mornings is a necessary measure to avoid damage (Lebot, 2009). Further, planting cocoyam directly into a mulch controls weeds to a great extent. Legume such as (*Pueraria* or *Mucuna* spp.) is used as a cover crop during the fallow and then killed to produce a thick cover of dried biomass and the propagules are planted through holes dug through the mulch.

Harvesting

Cocoyam is mature when the leaf petioles and blades reduce in size, decrease in the regeneration of young leaves and the well-formed corms begin to reduce in diameter near the petiole and form a 'bottleneck' shape. Cocoyam is harvested by pulling strongly on the petiole or uplifting the corm gently with a flat-bladed fork. The roots are then cut and trimmed off the corm to obtain a smooth surface. The petiole is cut approximately 30 cm above the corm to ease their handling and prevent desiccation. Harvesting can be piecemeal, removing cormels of a satisfactory size while leaving others to develop further (Lebot, 2009). In very humid locations, cocoyam is grown as a biennial or perennial crop, and multiple harvesting is practised. Under these conditions yield varies from 12 to 37 t/ha depending on the place, conditions and method of production. The leaf area or leaf area index has consistently been shown to correlate with corm and cormel yields. Pronounced reduction in leaf area, mainly during the growth and development cycle, results in reduced corm and cormels production (Reyes, 2006). The cormels are usually stored in well-shaded and ventilated conditions. A study in Nigeria investigated the influence of harvesting time on the yield, protein and ash components of cocoyam. The percent protein content in the leaves, cormels and corms was highest at 12 WAP, whereas ash content increases with delayed harvesting (Ndon *et al*., 2003). Mechanized harvesting is possible when plants are established on loose and light soil, in lines suitably spaced, allowing a tractor-drawn harvester similar to the type used for carrots. The harvester is designed with an adjustable flat blade, 1.2 - 1.5 m wide, which cuts the roots at a depth of about 20 cm. Workers following behind the tractor pull the plants up gently with lesser effort. This type of mechanized harvesting approach has been successfully tested in New Caledonia and is quite efficient when the plants have not been planted too deep. It is time-saving and yield loss is minimal, with reduction in labour costs (Lebot, 2009).

Factors affecting cocoyam cultivation in Nigeria

The persistent lower yields are generally impeding cocoyam production in Nigeria and this is driven by the continued use of propagules from low-yielding cultivars. Cocoyam production has remained at the subsistence level with the farmers diligently practising low-input cropping systems. The reuse or recycling of seed - vegetatively propagated material without sanitation measures has led to a gradual decrease in yield over the years (Reyes, 2006). Pests and diseases, poor agronomic practices, infertile soils and lack of improved technologies are also hampering the crop's production on a large scale. For instance, the emergence of taro leaf blight (TLB) (*Phytophthora colocasiae*) resulted in high economic loss, with a huge impact on the genetic erosion of the gene pool, accounting for about 60 % of losses encountered (Onyeka, 2014; Otekunrin *et al*., 2021). Further, the corms of especially taro can rotten as early as two weeks after harvest, causing about 90 % loss within six months after harvest, when not treated with pre-storage fungicide and sodium hypochlorite applications as dips within 24 hours after harvest (Owusu-Darko *et al*., 2014). The inadequate research and policy interventions that will increase productivity, encourage innovations and create market outlets for cocoyam discourage farmers and investors, when compared to other root and tuber crops. There's a high chance that cocoyam's productivity and production will increase tremendously when these factors hampering its cultivation are addressed.

Discussion

This review provided insight into the physiology of cocoyam, good agronomic practices that could optimize the yield per unit land area and its responses to different growing conditions. Research should be targeted towards the selection of high-yielding and disease-resistant varieties to support low-cost technologies that will increase productivity and production. In Nigeria, there are yet no improved varieties of cocoyam that are resistant to most of the dreaded diseases such as leaf blight. Cocoyam production is highly relying on a few genotypes, and research focusing on evaluating the disease tolerance and resistance of different genotypes, selecting desired traits from wild cocoyam relatives has become inevitable. Due to the lack of resistant genotypes, the only immediate possible way to reduce disease load, curtail disease prevalence and increase productivity is by cleaning the planting materials and making them available to farmers. However, the low price of cocoyam in the local market makes the cleaning and production based directly on *in vitro* plants non-profitable. A more economically viable alternative would therefore be to distribute planting material in the form of cormels produced from *in vitro* plants to the farmers.

Factors responsible for the decline in cocoyam production are multifaceted. From continued neglect of the crop by farmers and research scientists, poor cropping system, to loss of interest in consumption due to its limited availability in the market (Abdulrahman *et al*., 2015) and growing food preferences. However, the neglected crop has many other benefits that are repositioning it to regain its importance and global relevance. With climate change having significant, often negative impacts on farming systems around the world, it is predicted that the tropics in general, will suffer the most from the effects of increased and sporadic temperature spikes, drought, erratic rainfall, salinity and flooding (IPPC 2007; Raji and Byju, 2020; Yamanouchi *et al*., 2022). Most crops currently grown by farmers are vulnerable to these stresses, with resultant losses in productivity, and potentially negative consequences for food security. For instance, cassava with all its admirable attributes is susceptible to flooding, dying within 24 hours of flooding. In Nigeria, the demand for food keeps increasing with the population, therefore requiring more land area and this has pushed the cultivation of crops into areas which are prone to flooding. Major crop growing areas have recently been regularly flooded, particularly at the peak of the rainy season. Cocoyam–taro's ability to thrive in waterlogged conditions makes it a reliable food crop in a changing climate. Also, its ability to grow under certain shade levels makes it a choice crop for enhancing agrobiodiversity and agroforestry cropping systems, thereby mitigating climate change effects and risks. Advocacy to grow more taro in the region will be the right step in the right direction.

Conclusion

Cocoyam can play a sustainable significant role in contributing to food security and enhancing agrobiodiversity in the face of climate change. The need for studies that will help harness the potential of the crop in Nigeria and in reducing climate risks has become important. Research should focus on the use of advanced biotechnology tools to generate cultivars that are high yielding, disease resistant with increased palatability to win the interest of consumers. The cultivation of flood-tolerant taro in Nigeria should be encouraged as it also reduces demand for herbicides and pesticides, thereby protecting the environment.

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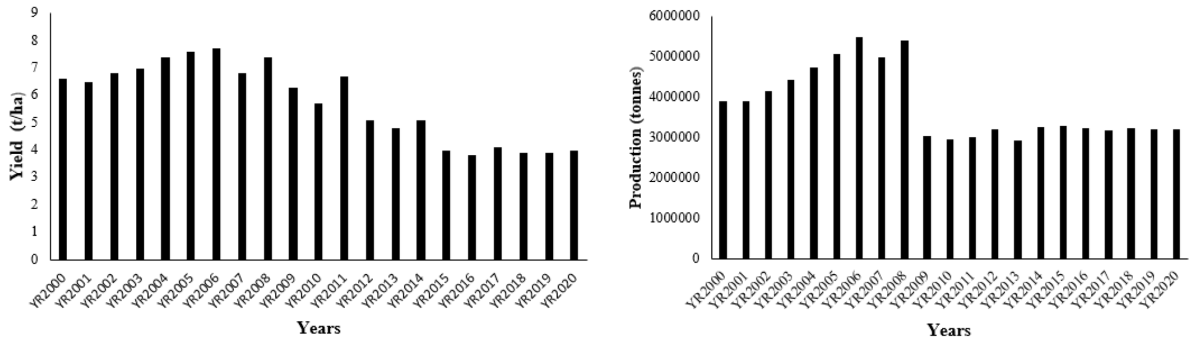

Fig. 1: Yield per unit land area and production of cocoyam between 2000 and 2020 in Nigeria (FAOSTAT, 2022)

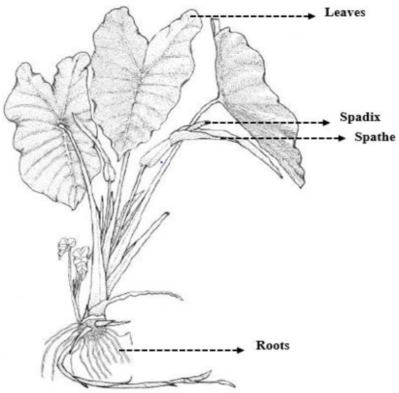

Fig. 3: Young cocoyam plant showing the leaves, spadix, spathe and roots.
Source: Lebot, 2009

Table 1: Biomass production and dry matter content of unfertilized and fertilized taro

	Midseason (126 DAP)		**At harvest (231 DAP)**		
	Plant part	**Unfertilized**	**Fertilized**	**Unfertilized**	**Fertilized**
Dry weight (t/ha)	Roots	0.26	0.52**	0.51	0.50
	Corms	0.82	1.21	2.53	6.99*
	Leaves	0.68	2.13*	2.00	3.64*
	Total	1.75	3.86*	5.04	11.13*
Dry matter (%)	Roots	4	5**	12	11
	Corms	21	19	30	30
	Leaves	8	7	16	16

Source: Lebot (2009)
Note: Leaf biomass includes petioles. * and ** indicate significant differences at $P < 0.05$ ***and*** $P < 0.001$***, respectively***

Table 2: Effect of K on the number of cormels per plant of cocoyam 9 months after planting

Application	**175 K (kg/ha)**	**200**	**225**	**250**	**275**	**LSD** $p = 0.05$
Basal	5.2	5.7	7.1	10.6	9.8	0.84
Split	3.1	4.3	5.4	5.8	6.1	0.59

Source: Sangakkara (1990)
Note: Basal = all K at planting. Split = 100 kg K2O/ha at 90 DAP, the remainder at planting

Table 3: Recommended fertilizer rates for tannia and taro clones

Elements	**Taro**	**Tannia**
N	260–340	100–130
P_2O_5	80–100	40–50
K_2O	280–380	130–190

Table 4: Taro corm yield and growth measurements as affected by intercropping

Intercrops	Corm yield (t/ha)	Growth height (cm)	Suckers/plant
Control (no intercrop)	37.04	100	7.5
Bush beans	45.57	98	8.5
Lucerne	49.80	105	9.0
Sweetcorn	39.95	102	8.7
Sweet potato	40.19	88	3.2
Groundnut	50.58	103	7.7
LSD (0.05)	ns	13	3.2

Source: Lebot, 2009