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# REVIEW ARTICLE

## ORIGIN, DISTRIBUTION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF CASSAVA

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**ABSTRACT**

Cassava belongs to the family *Euphorbiaceae,* subfamily *Crotonoideae*, tribe *Manihoteae*, genus *Manihot* and species *Manihot esculenta* Crantz. Cassava is a dicot perennial shrub. It is known as tapioca, manioc, mandioca or yuca in different parts of the world. It can reach a height of 1-4 m. Its tuberous storage roots are rich in starch (20-40%) and are harvested either for direct human consumption, animal feed, or industrial uses. It is also known as cassada, cassava, manioc, yuca, tapioca, mandioca, shushu, muk shue, cassave, maniok, tapioka, imanoka, maniba, kasaba, katela boodin, manioc, manihot, yucca, mandioca, sweet potato tree, and tapioca plant. The generic name *Manihot* and the common name "manioc" both derive from the Guarani (Tupi) name *mandioca* or *manioca* for the plant. The specific name *esculenta* is Latin for 'edible'. The common name "cassava" is a 16th century word from the French or Portuguese *cassave*, in turn from Taíno *caçabi*.[4] The common name "yuca" or "yucca" is most likely also from Taíno, via Spanish *yuca* or *juca.* Cassava, also known as manioc or yuca, is a starchy root vegetable that has played a crucial role in the diets of people across the globe for centuries. Its significance as a staple food has transcended geographical boundaries and cultural differences, making it a truly universal crop. With its origins in South America, cassava has a rich history that dates back thousands of years, and its journey from being a wild plant to a vital food source for millions of people is nothing short of remarkable. The story of cassava is one of resilience and adaptability, as it has managed to thrive in a variety of climates and soil conditions. Its versatility as a food source, from being consumed as a whole root to being processed into flour and other products, has contributed to its widespread popularity. As we delve into the history of cassava as a staple food, it becomes evident that its impact goes far beyond mere sustenance, playing a significant role in shaping the cultural, social, and economic landscapes of the regions where it is grown and consumed. From its role in traditional rituals and ceremonies to its importance in local cuisines, cassava has been deeply woven into the fabric of many societies. Its journey from being a local food source to a global commodity has not been without challenges, and its history is marked by moments of triumph and adversity. As we explore the multifaceted nature of cassava's history, we gain a deeper understanding of its enduring significance and the ways in which it has shaped the lives of people around the world. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding of Cassava are discussed.



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# INTRODUCTION

Cassava belongs to the family *Euphorbiaceae,* subfamily *Crotonoideae*, tribe *Manihoteae*, genus *Manihot* and species *Manihot esculenta* Crantz (NWC, 2024; Wikipedia. 2024). Cassava is a dicot perennial shrub. It is known as tapioca, manioc, mandioca or yuca in different parts of the world. It can reach a height of 1-4 m. Its tuberous storage roots are rich in starch (20-40%) and are harvested either for direct human consumption, animal feed, or industrial uses (Fei *et al*, 2023); cassada, cassava, manioc, yuca, tapioca, mandioca, shushu, muk shue, cassave, maniok, tapioka, imanoka, maniba, kasaba, katela boodin, manioc, manihot, yucca, mandioca, sweet potato tree, and tapioca plant **(**Moore and Lawrence, 2024**).** The generic name *Manihot* and the common name "manioc" both derive from the Guarani (Tupi) name *mandioca* or *manioca* for the plant. The specific name *esculenta* is Latin for 'edible'. The common name "cassava" is a 16th century word from the French or Portuguese *cassave*, in turn from Taíno *caçabi*.[4] The common name "yuca" or "yucca" is most likely also from Taíno, via Spanish *yuca* or *juca* (Wikipedia. 2024).

Cassava is propagated by cutting a mature stem into sections of approximately 15 centimeters and planting these prior to the wet season. These plantings require adequate moisture during the first two to three months, but subsequently are drought resistant. The roots are harvestable after six to twelve months and can be harvested any time in the following two years, providing farmers with a remarkable amount of flexibility. Cassava is harvested by hand by raising the lower part of stem and pulling the roots out of the ground, then removing them from the base of the plant. The upper parts of the stems with the leaves are plucked off before harvest. Roots using deteriorate within three to four days after harvesting and thus are either consumed immediately or processed into a form with better storage qualities. Starch-rich storage roots of cassava are a major food staple in Africa and provide calories for nearly half a billion people worldwide. Africa contributes 61% of global cassava production, followed by Asia (29.5%) and Americas (9.5%). There is a need for breeders to tap into a broader spectrum of genetic diversity if the full potential of this crop is to be realised. Cassava is clonally propagated through stem cuttings with a typical 12-month cropping cycle. Botanical seed is produced with separate male and female flowers that are adapted for outcrossing (Ferguson *et al*, 2019).

The origin of cassava can be traced to South America, the Cerrado, in present-day Brazil. Cassava was first domesticated in West-Central Brazil around 10,000 years ago (Lebot, 2020). Today it is cultivated in tropical regions worldwide and is the sixth most important crop plant worldwide. Cassava is a drought-tolerant crop that can survive hot climates with little rainfall. The plant can be grown throughout the year under severe climates of marginal soils of low nutrients (Lebot, 2020). Today, cassava is used as a staple food in different parts of the world and for food security. Millions of farmers around the world make a living from cultivating this crop (Lebot, 2020). There are two types of cassava varieties, namely, sweet and bitter cassava varieties. The sole difference between the two cassava varieties is the number of cyanide compounds they produce (Lebot, 2020). Though both varieties are cultivated in the same way, the bitter variety produces a higher amount of cyanide compounds in the cassava tubers than the sweet variety. For instance, sweet cassava varieties may contain as few as 40 parts per million (ppm) cyanide compounds in cassava tubers. It does not require much processing before it is safe to eat, making it less poisonous. The cassava tubers are only safe to eat when cyanide compounds are removed from the tubers (Lebot, 2020). Bitter cassava varieties contained over 50 parts per million (ppm) cyanide compounds. Research shows that bitter cassava varieties contain high as 490 parts per million (ppm) cyanide compounds (Lebot, 2020). It has been documented that any quantity over 50 parts of cyanogens per million is said to be harmful and unsafe for consumption. Cyanide compounds present in cassava constitute a huge threat to health and can even cause death if the cyanide compounds are not processed before consumption (Lebot, 2020). Several methods can be applied to process cyanide compounds from cassava. Namely, drying, soaking, boiling, and roasting. While drying reduces the level of cyanide, it does not remove it from cassava, making it not adequately safe for consumption. The other methods can reduce the cyanide content to manageable levels for safe consumption (Lebot, 2020).

Cassava, also called manioc, mandioca, or yuca, is a tuberous edible, slightly woody, and shrubby plant belonging to the spurge family (*Euphorbiaceae*) that typically grows from one to three meters in height. It is a perennial plant, and it is characterized by fan-lobed leaves, starchy, tuberous roots, papery brown bark, and white to yellow flesh. The cassava root is long, about 1 mm thick, with rough and brown skin (Lebot, 2020). There are different varieties of cassava, from low herbs to branching shrubs. Some of these varieties are adapted to acid mud banks along rivers, and others are dry areas of alkaline soil. The chemical compounds (cyanogenic glucosides) in the roots and leaves of cassava offer some protection against some herbivores animals. This chemical compound can be toxic to humans if consumed without treatment and processing (Lebot, 2020). Because cassava can survive and grow in non-humid environments, it is replacing some other root crops, such as yam, which require higher soil fertility to grow and are easily infested with pests. Except for sugarcane, the cassava plant gives the highest yield of food energy among crop plants per cultivated area daily (Lebot, 2020). Cassava is grown by cutting a mature stem into sections 15 centimetres. The planting of cassava planting requires adequate moisture during the first two to three months. Usually, planting takes place during the wet season. However, the plants are drought resistant (Lebot, 2020). The roots are a very popular food and are harvestable after six to twelve months. Cassava is harvested by hand. This is done by raising the lower part of the stem and pulling the roots out of the ground. After harvesting, it is either consumed immediately or processed into a form with better storage qualities. Because it takes three to five days to decay. Cassava roots can be stored in the ground for as long as 24 months (Lebot, 2020).

The agricultural sector is key to economic growth in Africa. The recent report on the Global Hunger Index indicates that over half of the world's food-insecure people live in Africa. Sustainable agricultural production is imperative to curb food insecurity, reduce poverty, and impact the livelihood of smallholder farmers. Cassava is among the six commodities defined by the African Heads of States as strategic crops for the continent, given its significant contribution to the livelihoods of African farmers and its potential for transforming African economies (Mbanjo *et al.,* 2020). Cassava is a root crop grown throughout the tropics by more than 800 million people. It can grow with minimal inputs under marginal soil conditions and in regions prone to drought. Though mainly cultivated for its starchy roots, nutrient-dense cassava leaves are also consumed as vegetables in many regions of Africa. Due to its long harvest window, cassava roots are used as a food reserve during periods of food shortage or during the lean season before harvest of other crops. Although its cultivation has traditionally been associated with subsistence farming, the crop is gradually becoming an industrial crop, which is processed into different products, including bread, pasta, and couscous-like products. Apart from the food industry, cassava starch is used for textiles, the paper industry, in the manufacture of plywood and veneer adhesives, glucose and dextrin syrups (Mbanjo *et al*., 2020).

Cassava is the sixth most important food crop and consumed by 800 million people worldwide. In Africa, cassava is the second most important food crop after maize and Africa is the worlds' largest producer. Though cassava is not one of the main commodity crops in South Africa, it is becoming a popular crop among farming communities in frost-free areas, due to its climate-resilient nature (Amelewor and Bairu, 2022).

With increasing climate variability, cassava has attained significant importance in worldwide agriculture. It is an attractive food security and commercial crop for subsistence farmers with limited resources and it can grow in marginal soils. Cassava roots are the main carbohydrate storage organs and store up to 85% starch on a dry weight basis. Cassava roots contain a starch content of 40% higher than rice and 25% more than maize. It is estimated that in South Africa, maize accounts for approximately 95% of the country's starch production, with 37% of the produce being used for food, 40% for feed, 18% for export, and 5% for starch. Due to drought and competition between industries utilizing maize products, the local starch industries failed to meet the starch demand of the country. Hence, South Africa is importing more than 66,000 tons of starch annually. It was reported that cassava starch is preferred in South Africa in terms of imports and it fetches a higher price on the market than maize, potato, or wheat. Hence, grasping the industrial potential of cassava in the starch industry would satisfy local starch demands, avoid computation among staple food commodities, and reduce import volume (Amelewor and Bairu, 2022). Cassava can be used as an alternative food security and industrial crop in South Africa. It can grow and produce reasonable yields in areas where cereals and other crops are not viable. It can tolerate drought and can be grown on soils with low soil fertility but responds well to irrigation and fertilizers. However, it has received little research priority and a limited number of genotypes have been tested. The currently available wide genetic resources maintained in international and regional research institutes should be explored for traits such as quality, yield potential, and biotic and abiotic stress tolerance. These will identify promising genotypes, which may facilitate development of genetically superior and improved cassava cultivars for South Africa. In addition, exploiting the industrial potential of cassava in South Africa will improve rural livelihoods through income generation and job creation. Furthermore, the national economy should benefit indirectly from job creation, and directly from foreign exchange savings originating from replacing imported products and raw materials (Amelewor and Bairu, 2022).

Cassava, an ancient tropical root vegetable from Latin America, is one of the world's oldest food crops and holds the fifth position in terms of calorie consumption in the global scenario. It is an essential source of food for millions of people worldwide and is extensively cultivated in the subtropical and tropical areas of the world by small farmers. The crop is annually grown for its edible starchy tuberous root, a rich source of carbohydrates. Apart from being used for human consumption and as animal feed, cassava plays a significant role in the industrial sector as it is the second most relevant and reliable source of starch worldwide, just after maize. Owing to its growing importance as a source of food and industrial processing material, and as an energy crop, cassava is also known as the "king of starch" and "the underground granary" (Sivan *et al.,* 2023). Applications of starch extracted from cassava tubers are found in the pharmaceutical and textile industry and within food manufacturing, where it is best suited due to its bland taste. Regionally, cassava is also a major source of bioethanol production. The rising demand for cassava starch and non-grain-derived biofuels has enhanced the expansion of cassava cultivation around the globe (Sivan *et al.,* 2023). Cassava is a highly heterozygous crop. The major genetic improvement method adopted in cassava includes its assemblage of germplasm and followed by the selection of superior/elite parents for the process of hybridization . The characterization of various germplasm primarily depends on genetic variability, its type of reproduction, and the breeding objective. A prerequisite for any breeding programme is a basic understanding of the magnitude of the diversity present in the germplasm. With a clear understanding of the genetic diversity of species, suitable breeding programs and strategies for developing germplasm collection, conservation and advancement for food security and sustainable agricultural development can be carried out. Genetic diversity studies in cassava are carried out by adopting a combination of morphological and molecular methods. For the study of cassava diversity, several molecular markers are being used (Sivan *et al*., 2023).

Cassava is recognized as one of the most important tuber crops cultivated in tropical and subtropic regions, providing a major source of food to more than 800 million people worldwide. The cassava plant is a perennial woody shrub that can grow up to three meters in tropical regions. The plant is believed to have originated in Latin America, where the native Indians discovered it more than 4000 years ago (Mohidin *et al*., 2023). It is described as a dicotyledonous plant belonging to a genus of *Euphorbiaceae* family called *Manihot*, and it is grown in areas between 30°N and 30°S from the equator, where it is distributed throughout Africa, Asia, Central and South America. Given that cassava is considered a dietary staple food in many countries, including the Democratic Republic of Congo, Ghana, Brazil, and Indonesia, Nigeria is recognized as the world's largest cassava producer, producing over 60 million tonnes in 2020 (Mohidin *et al*., 2023). Moreover, cassava is among Thailand's main economic crops, which was established as the largest dried cassava, flour, and starch exporter in 2020. Despite having this nutritional and economic importance in numerous countries, cassava crops are underutilized in some countries due to higher demand for cereal crops, lack of accessibility to grow cassava on a large scale in addition to farmers' lack of knowledge on the cultivation of cassava varieties with better properties. In South Africa, the crop is primarily cultivated by small-scale farmers in rural areas for food, while Pietersburg is the only area with a starch manufacturing factory for commercial farming of cassava (Mohidin *et al*., 2023). A wide range of cassava varieties was tested for producing high-quality cassava flour. β-carotene enriched cassava varieties have illustrated high viscosity values suitable for products requiring high gel strength and elasticity. Furthermore, enriching flour produced from low- and medium-cyanide cassava varieties with nutrients was more efficient with certain micro-fungi such as *Saccharomyces cerevisiae* (Mohidin *et al.,* 2023).

The most diverse cassava germplasm collection is preserved by the International Center for Tropical Agriculture (CIAT), and over 43 000 samples of cassava germplasm samples have been distributed to 84 countries since 1979. For instance, Naitaima-31 is a cassava variety released by CIAT and their partners, which has been developed by crossing two germplasms to possess the following properties: large harvest, good cooking qualities, and resistance against whiteflies. In contrast to the farmer's varieties, Naitama-31 has indeed produced higher yields without the need to use pesticides and is now cultivated for commercial purposes in Brazil and Colombia (Mohidin *et al*., 2023). The variety of yellow cassava was exploited in the beverages industry, as its use as a raw material for beer production has been found to be beneficial not only nutritionally but also in terms of cutting overhead costs of production. A study has shown that beer produced from blending sorghum with yellow cassava could be a rich source of nutrients and vitamins. (Mohidin *et al.,* 2023). Additionally, cassava contains various chemical components. These components include balanophonin, scopoletin, and tannins which have been studied to exhibit anti-oxidant activity, anti-proliferative and anti-inflammatory properties. Besides these beneficial phytochemicals, toxic chemical compounds – linamarin and lotaustralin are cyanogenic glycosides that can also be found in cassava leaves and roots. These components are known to be detrimental to human health as they may contribute to developing neurological disorders, especially when consuming raw cassava or long-term consumption of incorrectly processed tubers. Hence, cassava should be processed appropriately before consumption as various effective detoxification methods are available for cassava to be eaten safely, such as drying and boiling (Mohidin *et al.,* 2023).

Cassava, also known as manioc or yuca, is a starchy root vegetable that has played a crucial role in the diets of people across the globe for centuries. Its significance as a staple food has transcended geographical boundaries and cultural differences, making it a truly universal crop (Savory, 2023). With its origins in South America, cassava has a rich history that dates back thousands of years, and its journey from being a wild plant to a vital food source for millions of people is nothing short of remarkable (Savory, 2023). The story of cassava is one of resilience and adaptability, as it has managed to thrive in a variety of climates and soil conditions. Its versatility as a food source, from being consumed as a whole root to being processed into flour and other products, has contributed to its widespread popularity (Savory, 2023). As we delve into the history of cassava as a staple food, it becomes evident that its impact goes far beyond mere sustenance, playing a significant role in shaping the cultural, social, and economic landscapes of the regions where it is grown and consumed (Savory, 2023). From its role in traditional rituals and ceremonies to its importance in local cuisines, cassava has been deeply woven into the fabric of many societies. Its journey from being a local food source to a global commodity has not been without challenges, and its history is marked by moments of triumph and adversity. As we explore the multifaceted nature of cassava's history, we gain a deeper understanding of its enduring significance and the ways in which it has shaped the lives of people around the world (Savory, 2023).

Cassava is a woody shrub of the spurge family, Euphorbiaceae, native to South America, from Brazil, Paraguay and parts of the Andes. Although a perennial plant, cassava is extensively cultivated in tropical and subtropical regions as an annual crop for its edible starchy root tuber. Cassava is predominantly consumed in boiled form, but substantial quantities are processed to extract cassava starch, called tapioca, which is used for food, animal feed, and industrial purposes. The Brazilian *farinha*, and the related *garri* of West Africa, is an edible coarse flour obtained by grating cassava roots, pressing moisture off the obtained grated pulp, and finally drying it (and roasting in the case of both *farinha* and *garri*) (Wikipedia. 2024). Cassava is the third-largest source of carbohydrates in food in the tropics, after rice and maize, making it an important staple; more than 500 million people depend on it. It offers the advantage of being exceptionally drought-tolerant, and able to grow productively on poor soil. The largest producer is Nigeria, while Thailand is the largest exporter of cassava starch (Wikipedia. 2024). Cassava is grown in sweet and bitter varieties; both contain toxins, but the bitter varieties have them in much larger amounts. Cassava has to be prepared carefully for consumption, as improperly prepared material can contain sufficient cyanide to cause poisoning. The more toxic varieties of cassava have been used in some places as famine food during times of food insecurity. Farmers may however choose bitter cultivars to minimise crop losses (Wikipedia. 2024).

Cassava, tuberous edible plant of the spurge family (*Euphorbiaceae*) from the American tropics. It is cultivated throughout the tropical world for its tuberous roots, from which cassava flour, breads, tapioca, a laundry starch, and an alcoholic beverage are derived. Cassava probably was first cultivated by the Maya in Yucatán (Petruzzello, 2024). Cassava is a tuberous, woody, shruby perennial plant, *Manihot esculenta*, of the Euphorbiaceae (spurge family), characterized by palmately lobed leaves, inconspicuous flowers, and a large, starchy, tuberous root with a tough, papery brown bark and white to yellow flesh. The name cassava also is used for this tuber, which is a major source of carbohydrates and is a dietary staple in many tropical nations. This plant and root also are known as yuca, manioc, and mandioca (NWC, 2024). While native to South America, cassava now is extensively cultivated as an annual crop in many tropical and subtropical regions of the world, including Africa, India, and Indonesia, with Africa its largest center of production. This is a prolific crop that can grow in poor soil and is drought tolerant. It is the one of the most important food plants in the tropics and the third largest source of carbohydrates for human food in the world (NWC, 2024). The roots and leaves contain cyanogenic glucosides, which offer a protection against some herbivores, but also make the plant toxic to humans if consumed without prior treatment, such as leaching and drying. In particular, the varieties known as "bitter cassava" contain significant amounts of cyanide, with the "sweet cassava" less toxic. It is a unique aspect of human beings to be able to process toxic plants into a form that makes them edible (NWC, 2024). Cassava is the source of flour called tapioca, as well as is used for breads, and alcoholic beverages. The leaves also can be treated and eaten. However, cassava is a poor source of protein and reliance on cassava as a staple food is associated with the disease kwashiorkor (NWC, 2024).

In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding of Cassava are discussed.

## ORIGIN AND DISTRIBUTION

Cassava is a staple crop with great economic importance worldwide, yet its evolutionary and geographical origins have remained unresolved and controversial. We have investigated this crop's domestication in a phylogeographic study based on the single-copy nuclear gene glyceraldehyde 3-phosphate dehydrogenase (*G3pdh*). The *G3pdh* locus provides high levels of noncoding sequence variation in cassava and its wild relatives, with 28 haplotypes identified among 212 individuals (424 alleles) examined. These data represent one of the first uses of a single-copy nuclear gene in a plant phylogeographic study and yield several important insights into cassava's evolutionary origin: (*i*) cassava was likely domesticated from wild *M. esculenta* populations along the southern border of the Amazon basin; (*ii*) the crop does not seem to be derived from several progenitor species, as previously proposed; and (*iii*) cassava does not share haplotypes with *Manihot pruinosa*, a closely related, potentially hybridizing species. These findings provide the clearest picture to date on cassava's origin. When considered in a genealogical context, relationships among the *G3pdh* haplotypes are incongruent with taxonomic boundaries, both within *M. esculenta* and at the interspecific level; this incongruence is probably a result of lineage sorting among these recently diverged taxa. Although phylogeographic studies in animals have provided many new evolutionary insights, application of phylogeography in plants has been hampered by difficulty in obtaining phylogenetically informative intraspecific variation. This study demonstrates that single-copy nuclear genes can provide a useful source of informative variation in plants (Olsen and Schaal, 1999).

The origins of cassava (*Manihot esculenta* Crantz subspecies *esculenta*) have long been obscure. The three important questions to answer concern the botanical origin, (*i.e.* the wild species from which cassava descends), the geographical origin, (*i.e.* the area where the progenitor evolved in the geological past) and the agricultural origin (*i.e.* the area of initial cultivation of the wild ancestor by Amerindians). In turn, this would indicate the ancestry of the crop (the evolution of the ancestor and its phylogenetic relationships with related species) and the cradle of domestication. Current knowledge on the three topics shows that studies on the botanical origin of cassava have progressed far and stand on firm ground, those on the geographical origin have progressed and conjecture on the area where cultivation began has recently experienced a renewed surge following the appearance of novel ideas. Studies on the taxonomy of the genus *Manihot* in Brazil led unexpectedly to progress in matters with a bearing on the origins and phylogeny of cassava. Accumulated empirical knowledge derived from field experience culminated with the formulation of a classification in which the Brazilian species were arranged in groups. The model of classification proposed was thought to mirror some degree of phyletic kinship between the species. Group VI in particular, the *M. esculenta* group, has been tested extensively by the scientific community through genetic studies and phylogenetic investigations, which in turn influenced cladistic and taxonomic classifications. This group is particularly highlighted in the present review (Allem, 2002).

The center of origin for cassava is in Central and South America although the specific geographic origins are still debated. Evidence based on molecular markers suggests that it was domesticated as much as 10,000 years ago, within the south-western rim of the Amazon basin (in modern day Brazil), and is derived from its closest wild relative, *Manihot esculenta* ssp. *flabellifolia* (Pohl), a perennial woody shrub. During the 16th century Portuguese traders introduced cassava to the western shores of Africa, initially to provide provisions for slave ships. More-or-less simultaneous introductions were made through various Portuguese trading stations in the Gulf of Guinea, Sierra Leone and along the coasts of Angola and DRC, between Luanda and the mouth of the Congo River. Subsequent diffusion of the crop inland was slow, but by the time of the European explorations into the interior in the 19th century, cassava cultivation had become widespread throughout much of tropical West, Central and East Africa. Information on the introduction of cassava to East Africa is more speculative, but it appears to have been introduced through the Portuguese trading posts of Moçambique Island, Sofala, Kilwa, Benguela, Mombasa, Zanzibar and Pemba during the 17$^{th}$ and 18$^{th}$ centuries. It appears that the inland spread of cassava from the East African coast was limited, with cassava reaching the highlands of Rwanda and Burundi from the west and the upper Zambezi from Angola (Ferguson *et al,* 2019).

Cassava belongs to the family *Euphorbiaceae*, sub-family *Crotonoideae*, tribe *Manihotae*, and genus *Manihot*. The genus has two sections, the Arborae, containing tree species, and the Fructicosae, comprising slow-growing shrubs adapted to savannah grassland or desert conditions. The genus Manihot is a large family of flowering plants with 300 genera and around 8000 species. Of the many species that belong to the genus Manihot, *Manihot esculenta* Crantz is the most economically important species and widely cultivated for food and industrial applications (Amelewor and Bairu, 2022). Cassava is believed to have been domesticated before 4000 BC, and its center of origin is hypothesized to be South America. The questions about the wild progenitor of cassava, the area where the wild progenitor evolved and was initially cultivated have been obscured. Originally, it was speculated that cassava could be ascended and evolved via periodic introgression of genes involving a number of wild species (compile-species). However, later it was reported that a wild species, *Manihot flabellifolia* (Pohl), was found to be the closest wild relative to cassava. Many studies have supported the ancestral relationship of the modern cultivated cassava and the wild subspecies *M. esculenta* ssp. *Flabellifolia* (Amelewor and Bairu, 2022). The exact geographical origin of the crop has been disputed for many years following the appearance of new evidence. Geographic origin infers the distribution and habitats of the wild cassava species. Although controversial results have been reported, the southern border of the Amazon basin currently stands as the recognized center of origin for *M. esculenta.* A large number of wild Manihot species have been reported to be found in Brazil. Hence, this region is the likely primary center of diversity of cassava. The domestication process involved selection for root size, growth habit, stem number, and ability of clonal propagation through stem cuttings. During the 16th century, Portuguese traders introduced cassava to Africa and later to Asia. It was initially cultivated in the Democratic Republic of Congo and adopted as a famine-reserve crop. Currently, cassava is cultivated in about 40 African countries, stretching over a wide belt from Madagascar in the Southeast to Cape Verde in the Northwest (Amelewor and Bairu, 2022).

Cassava is widely believed to be originated from the southern rim of Amazonia. It is domesticated about 5,000-7,000 years BC and was introduced to Africa by Portuguese and Spanish explorers, likely in the sixteenth century. Cassava did not become popular in Asia until in the 1960s (Fei *et al,* 2023). The origins and domestication of cassava can be traced back to South America, where it has been cultivated for thousands of years. Believed to have originated in present-day Brazil, cassava was an essential crop for indigenous peoples in the region, providing a reliable source of sustenance in diverse environmental conditions. Through selective breeding and cultivation, early farmers developed different varieties of cassava with varying levels of toxicity, as the plant naturally produces cyanide compounds as a defense mechanism against herbivores (Savory, 2023).

Over time, cassava spread to other parts of South America, and its cultivation methods were refined, leading to increased yields and improved tolerance to different growing conditions. This allowed cassava to become a staple food in many indigenous cultures, contributing significantly to their dietary and cultural practices (Savory, 2023). The domestication of cassava eventually led to its introduction to Africa and Asia through trade and exploration. Portuguese explorers are credited with bringing cassava to Africa in the 16th century, where it quickly became a vital part of the local food supply. The crop's ability to thrive in poor soil and withstand harsh growing conditions made it particularly valuable in regions with unpredictable climates (Savory, 2023). As cassava cultivation spread across the globe, different varieties were developed to suit the specific needs of each region. This diversity in cassava strains contributed to its resilience and adaptability, ensuring its continued cultivation and consumption in various parts of the world (Savory, 2023). The domestication and spread of cassava not only transformed diets but also had a profound impact on the social and economic fabric of the societies that adopted it. It became an integral part of cultural practices, culinary traditions, and agricultural systems, shaping the way communities interacted with their environment and each other (Savory, 2023).

Wild populations of *M. esculenta* subspecies *flabellifolia*, shown to be the progenitor of domesticated cassava, are centered in west-central Brazil, where it was likely first domesticated no more than 10,000 years ago. Forms of the modern domesticated species can also be found growing in the wild in the south of Brazil. By 4600 BC, cassava pollen appears in the Gulf of Mexico lowlands, at the San Andrés archaeological site. The oldest direct evidence of cassava cultivation comes from a 1,400-year-old Maya site, Joya de Cerén, in El Salvador. It became a staple food of the native populations of northern South America, southern Mesoamerica, and the Taino people in the Caribbean islands, who grew it using a high-yielding form of shifting agriculture by the time of European contact in 1492. Cassava was a staple food of pre-Columbian peoples in the Americas and is often portrayed in indigenous art. The Moche people often depicted yuca in their ceramics. Spaniards in their early occupation of Caribbean islands did not want to eat cassava or maize, which they considered insubstantial, dangerous, and not nutritious. They much preferred foods from Spain, specifically wheat bread, olive oil, red wine, and meat, and considered maize and cassava damaging to Europeans. The cultivation and consumption of cassava were nonetheless continued in both Portuguese and Spanish America. Mass production of cassava bread became the first Cuban industry established by the Spanish. Ships departing to Europe from Cuban ports such as Havana, Santiago, Bayamo, and Baracoa carried goods to Spain, but sailors needed to be provisioned for the voyage. The Spanish also needed to replenish their boats with dried meat, water, fruit, and large amounts of cassava bread. Sailors complained that it caused them digestive problems. Portuguese traders introduced cassava to Africa from Brazil in the 16th century. Around the same period, it was also introduced to Asia through Columbian Exchange by Portuguese and Spanish traders, who planted it in their colonies in Goa, Malacca, Eastern Indonesia, Timor and the Philippines. Cassava has also become an important crop in Asia. While it is a valued food staple in parts of eastern Indonesia, it is primarily cultivated for starch extraction and bio-fuel production in Thailand, Cambodia and Vietnam. Cassava is sometimes described as the "bread of the tropics" (Wikipedia. 2024). There is a legend that cassava was introduced in 1880–1885 CE to the South Indian state of Kerala by the King of Travancore, Vishakham Thirunal Maharaja, after a great famine hit the kingdom, as a substitute for rice. However, there are documented cases of cassava cultivation in parts of the state before the time of Vishakham Thirunal Maharaja. Cassava is called kappa or maricheeni in Malayalam, and tapioca in Indian English usage (Wikipedia. 2024).

Cassava, commonly called manioc or tapioca, is a domesticated species of tuber, and the sixth most important food crop in the world. It was domesticated in the southwestern Amazon of Brazil and Bolivia some 8,000-10,000 years ago. Domesticate improvements include traits which must have been added by means of clonal propagation. Burned tubers of manioc were discovered at the classic Maya site of Ceren, dated to 600 CE. The progenitor of cassava (*M. esculenta ssp. flabellifolia*) exists today and is adapted to forest and savanna ecotones. The process of domestication improved the size and production level of its tubers, and increased the photosynthesis rate and seed functionality, by using repeated cycles of clonal propagation—wild manioc cannot be reproduced by stem cuttings. Identification of the Amazon as the point of origin was based on genetic studies of cultivated cassava and all various possible progenitors, and the Amazonian *M. esculenta ssp. flabellifolia* was determined to be the wild form of today's cassava plant (Hirst, 2024). Cassava starches have been identified in north-central Colombia by approximately 7,500 years ago, and in Panama at Aguadulce Shelter, about 6,900 years ago. Pollen grains from cultivated cassava have been found in archaeological sites in Belize and Mexico's Gulf coast by 5,800–4,500 bp, and in Puerto Rico between 3,300 and 2,900 years ago. Thus, scholars can safely say that the domestication in the Amazon had to happen before 7,500 years ago. There are numerous cassava and manioc species in the world today, and researchers still struggle with their differentiation, but recent research supports the notion that they are all descended from a single domestication event in the Amazon basin (Hirst, 2024).

Members of the Maya civilization cultivated the root crop and it may have been a staple in some parts of the Maya world. Manioc pollen has been discovered in the Maya region by the late Archaic period, and most of the Maya groups studied in the 20th century were found to cultivate manioc in their fields. The excavations at Ceren, a classic period Maya village that was destroyed (and preserved) by a volcanic eruption, identified manioc plants within the kitchen gardens. Manioc planting beds were discovered some 550 feet (170 meters) away from the village (Hirst, 2024). The manioc beds at Ceren date to approximately 600 CE. They consist of ridged fields, with the tubers planted on the top of the ridges and water allowed to drain and flow through the wales between the ridges (called calles). Archaeologists discovered five manioc tubers in the field which had been missed during harvesting. Stalks of manioc bushes had been cut into 1–1.5 meter lengths and buried horizontally in the beds shortly before the eruption: these represent preparation for the next crop. The eruption occurred in August of 595 CE, burying the field in nearly 3 m of volcanic ash (Hirst, 2024).

## TAXONOMY

Cassava (*Manihot esculenta* Crantz) does not grow wild. About 98 species are known to belong to the genus *Manihot,* ranging from subshrubs to shrubs and trees, the majority of them producing latex and containing cyanogenic glucosides. Unlike the cultivated species, the roots of wild species are fibrous and slender, but some species frequently exhibit a limited number of tuberous roots, the surfaces of which may be smooth or rough with a sub-epidermis varying from red or yellow to white, while the cortex of tuberous rooted species are white, cream or yellow (Nassar, 2000). Stem height varies from almost acaulescent in subshrubs to about 20 m in tree species. Shrub-type species native to the Brazilian savanna frequently have their stems die back to the crown in the dry season, while stem color varies from gray to brown or reddish. Stems normally branch in a dichotomous or trichotomous manner, with the branching point exhibiting a terminal inflorescence. In wild species the young stem frequently has a varying degree of pubescence, a character rarely encountered in the cultigens cassava (Nassar, 2000). Leaves are alternate, varying from subsessile to long petiolated and all except 3 species had palmately lobed leaf. Inflorescences are terminal and monoeceous with the exception of acaulescent species native to central Brazil. Flowers have a single perianth composed of 5 petals, with their length ranging from 0.5 to 2.0 cm. The buds of staminate flowers are ovoid or spheric, while those of pistillate flowers are conic. The fruits are capsular with three locules, while the seeds have a caruncle which varies in size. The chromosome number in all species investigated is 2n = 36 (Nassar, 2000). All species of the genus *Manihot* are native to countries of the New World, especially Brazil and Mexico, where they form distinct centers of diversity. They normally grow sporadically in their habitat and rarely become the dominant vegetation. Due to the monoeceous or dioecious structure of the inflorescence, wild *Manihot* species are typically alogamous plants, but in cultivated cassava a shift towards autogamous plants has occurred. Observations of frequent hybridization between the wild species and the cultigen as well as between the wild species themselves suggest weak inter-species fertilization barriers, probably due to the polyploidy nature of the genus (Nassar, 2000).

The genus *Manihot* contains more than 100 species, all naturally occurring between 33°N (southwest USA) and 33°S (Argentina). Wild relatives that have been used for interspecific hybridization include *M. catingae, M. dichotama, M. glaziovii, M. melanobasis* and *M. saxicola.* Among these, *M. glaziovii* (ceara rubbertree) is the only species that has made significant contributions in developing cassava germplasm resistant to cassava mosaic disease (Fei et al, 2023). Cassava belongs to the Euphorbiaceae family, which is made up of about 7200 species, characterized for their notable development of lactiferous vessels, themselves made up of secretory cells called lacticifers. These produce the milky secretion, or "latex", that characterizes the plants of this family. Plant architecture varies enormously within this family, ranging from arboreal types such as rubber (*Hevea brasiliensis*) to shrubs, also of economic importance, such as the castor-oil plant (*Ricinus communis*). Also representing this family are numerous weeds, ornamental plants, and medicinal plants. A highly significant genus of this family is *Manihot* to which cassava belongs (Ceballos and de la Cruz, 2024). The *Manihot* genus is native only to the Americas, with species being distributed from southwestern USA (33º N) to Argentina (33º S). Although all species of the genus can cross with each other, evidence suggests that, in nature, they are reproductively isolated. About 98 species have been described as belonging to this genus, of which only cassava (*Manihot esculenta* Crantz) has economic importance and is cultivated. Perhaps more than 100 common names now exist for this species, owing to its spread throughout the tropical world by early traders. In Latin America, it is usually known either as *yuca* (Spanish) or as *mandioca* (Portuguese). In Brazil, sweet cassava (*aipim*) is distinguished from bitter cassava (*mandioca*). Other names in different languages include manioc, manioca, tapioca, and *mhogo* (Ceballos and de la Cruz, 2024). The species *M. esculenta* be divided into three subspecies: *M. esculenta* subsp. *esculenta,* subsp. *flabellifolia*, and subsp. *peruviana*. The author also suggests that the last two subspecies are wild forms of the cultivated version *M. esculenta* subsp. *Esculenta* (Ceballos and de la Cruz, 2024).

**Synonym**

- *Janipha aipi* (Pohl) J.Presl
- *Janipha manihot* (L.) Kunth
- *Jatropha aipi* (Pohl) Göpp.
- *Jatropha diffusa* (Pohl) Steud.
- *Jatropha digitiformis* (Pohl) Steud.
- *Jatropha dulcis* J.F.Gmel.
- *Jatropha flabellifolia* (Pohl) Steud.
- *Jatropha loureiroi* (Pohl) Steud.
- *Jatropha manihot* L.
- *Jatropha mitis* Rottb.
- *Jatropha paniculata* Ruiz & Pav. ex Pax
- *Jatropha silvestris* Vell.
- *Jatropha stipulata* Vell.
- *Mandioca aipi* (Pohl) Link
- *Mandioca dulcis* (J.F.Gmel.) D.Parodi
- *Mandioca utilissima* (Pohl) Link
- *Manihot aipi* Pohl
- *Manihot aypi* Spruce
- *Manihot cannabina* Sweet
- *Manihot diffusa* Pohl
- *Manihot digitiformis* Pohl
- *Manihot dulcis* (J.F.Gmel.) Baill.
- *Manihot edule* A.Rich.
- *Manihot edulis* A.Rich.
- *Manihot flabellifolia* Pohl
- *Manihot flexuosa* Pax & K.Hoffm.
- *Manihot loureiroi* Pohl
- *Manihot melanobasis* Müll. Arg.
- *Manihot sprucei* Pax

*Manihot utilissima* Pohl

**Synonyms (**Moore and Lawrence, 2024**):**

- *Jatropha manihot* L.,
- *Janipha manihot* (L.) Kunth,
- *Manihot utilissima* Poh,
- *Manihot aipi* Poh,
- *Manihot manihot* (L.) Cockerell,
- *Manihot melanobasis* Muell. Arg.

## BOTANICAL DESCRIPTION

**Botanical Description:** The growth habit of cassava has important implications in cassava breeding as it can affect root yield. There are two growth types: 1) Erect growth type, with or without branching at the top. And 2) Spreading type, which is not cultivated. Branching occurs as a result of flower induction, therefore the branchings are often called "reproductive branchings". The branches can undergo further branching when flowering occurs, resulting in high order branching. Cassava roots are true roots, therefore cannot be used for propagation. Cassava root is the most economically important organ of a cassava plant because of the starch-containing cells in the parenchyma tissue, the edible part of the root. Only 3-10 of the fibrous roots of a cassava plant will eventually bulk and become storage roots through secondary growth while the rest of the fibrous roots remain thin and serve to function in water and nutrient absorption (Fei *et al*, 2023). Cassava is monoecious, producing separate male and female flowers on the same plant. Flowering in cassava is highly genotype and environment dependent. While some early-flowering genotypes can flower one month after planting, others may take 24 months to flower, consequently, synchronization of flowering time can be challenging in cassava breeding programs. Flowering rarely occurs during long dry period, thus irrigation is required for crossing blocks during an extended drought. Cassava inflorescence is developed from the fork of the branching. The female flowers which are larger in size but smaller in numbers than the male flowers are situated at the base of the inflorescence while the male flowers, often numerous are located on the upper part of the inflorescence. Female flowers open 1-2 weeks earlier than the male flowers on the same inflorescence. However, male and female flowers located on different inflorescences of the same plant can still open at the same time. Consequently, selfing can occur. Despite the occurrence of self-pollination, cassava is considered a cross-pollinated species and cross-pollination is done by insects. The average size of cassava pollen ranges from 122-148 µm, much larger and heavier than pollen of most other species. The longevity of cassava pollen is relatively short, lasting no more than 2 days. The degree of self-pollination depends on genotype, environmental conditions, and the presence of pollinating insects. Inbreeding depression is severe in cassava, thus seedlings of selfed progeny typically exhibit low vigor and lack competitiveness. Cassava fruit is a trilocular capsule, with each capsule containing a single seed. It takes 75-90 days after pollination for a cassava fruit to become physiologically mature. Dehiscing of mature cassava fruits is explosive, therefore bagging must be done before fruits become mature to collect seed in controlled crosses. Freshly harvested seeds are generally dormant and a 3-6 month of dry storage at ambient temperature is necessary to break the dormancy. Physiologically active cassava seed can germinate readily in about 15 days. The optimum temperature for germination is between 30-35°C. Cassava seed can be stored at 4-5°C and relative humidity of 60%. A germination percentage of greater than 80% has been reported for seed stored under such conditions for a year (Fei *et al*, 2023).

Cassava is a tall semi-woody perennial shrub or tree, up to 7 m high, single to few stems, sparingly branching; branchlets light green to tinged reddish, nodes reddish. The outer bark is smooth, light brown to yellowish grey; inner bark cream-green; exudate thin, watery; wood soft, creamy straw. *Leaves*: petiole light greenish to red; blade basally attached or slightly (up to 2 mm) peltate, dark green above, pale light greenish grayish underneath, sometimes variegated; lobes narrow, 2.9-12.5 times as long as wide; central unlobed part usually short, lobes 15-21 times as long. Inflorescences lax, with 35 together in fascicles; pedicels light green to red. *Staminate flowers*: calyx divided to halfway or more, green to white to lobes white to reddish with white median band inside to red purple, glabrous except for apex of calyx tube and inner side of segments finely hairy; filaments white, anthers yellow; disc yellow to light orange. *Pistillate flowers*: calyx green with red margin and midrib, hairy along the margin and on the midrib inside; disc pink; ovary with 6 longitudinal ridges, green (with pinkish stripes) to orange; pistil and stigmas white. *Fruit:* subglobose, green (to light yellow, white, dark brown), rather smooth, with 6 longitudinal wings. *Seeds:* Up to 12 mm long. *Root:* The tuberous edible root, grow in clusters of 48 at the stem base. Roots are from 1-4 inches in diameter and 8-15 inches long, although roots up to 3 feet long have been found. The pure white interior is firmer than potatoes and contains high starch content. The roots are covered with a thin reddish brown fibrous bark that is removed by scraping and peeling. The bark is reported to contain toxic hydrocyanic (prussic) acid, which must be removed by washing, scraping and heating **(**Moore and Lawrence, 2024**).**

Cassava, *Manihot esculenta*, is a perennial shrub in the family Euphorbiaceae grown primarily for its storage roots which are eaten as a vegetable. The cassava plant is a woody plant with erect stems and spirally arranged simple lobed leaves with petioles (leaf stems) up to 30 cm in length. The plant produces petal-less flowers on a raceme. The edible roots of the plant are usually cylindrical and tapered and are white, brown or reddish in color. Cassava plants can reach 4 m in height and is usually harvested 9-12 months after planting. Cassava may also be referred to as Brazilian arrowroot, manioc, yuca or tapioca and the origins of the plant are unknown. The plant is not known to occur wild but may have first been cultivated in Brazil. Cassava is the third-largest source of food carbohydrates in the tropics, after rice and maize. It is a major staple food in the developing world, providing a basic diet for over half a billion people. It is one of the most drought-tolerant crops, capable of growing on marginal soils (Anonymous, 2024). Cassava (*Manihot esculenta*), which is also called manioc, in cultivation in Uganda.(more) Cassava is a perennial plant with conspicuous, almost palmate (fan-shaped) leaves resembling those of the related castor-oil plant but more deeply parted into five to nine lobes. The fleshy roots are reminiscent of dahlia tubers. Different varieties range from low herbs to branching shrubs and slender unbranched trees. Some are adapted to dry areas of alkaline soil and others to acid mud banks along rivers (Petruzzello, 2024). The harvested part of a cassava plant is the root. This is long and tapered, with an easily detached rough brown rind. The white or yellowish flesh is firm and even in texture. Commercial cultivars can be 5 to 10 centimetres wide at the top, and some 15 to 30 cm long, with a woody vascular bundle running down the middle. The roots are largely starch, with small amounts of calcium (16 milligrams per 100 grams), phosphorus (27 mg/100 g), and vitamin C (20.6 mg/100 g). Cassava roots contains little protein, whereas the leaves are rich in protein, except for being low in methionine, an essential amino acid (Wikipedia. 2024). *Manihot esculenta,* or cassava, is a slightly woody, generally shruby plant that typically grows from one to three meters in height. The leaves are nearly palmate (fan- or hand-shaped) and dark green in color. There are over 5,000 varieties of cassava known, each with distinct qualities, and they range from low herbs to shrubs with many branches, to unbranched trees. The cassava root is long and tapered, with a firm homogeneous flesh encased in a detachable rind, about 1 millimeter thick, and rough and brown on the outside, just like a potato. Commercial varieties can be 5 to 10 centimeters in diameter at the top, and 50 to 80 centimeters long. A woody cordon runs along the root's axis. The flesh can be chalk-white or yellowish. Although there are many varieties of cassava, there are two main varieties, sweet and bitter. These are classified on the basis of how toxic are the levels of cyanogenic glucosides.The cassava plant gives the highest yield of food energy per cultivated area per day among crop plants, except possibly for sugarcane (NWC, 2024). Botanical description is given in Fig. 1. It is crucial to keep the soil well-drained and free of weeds during this period. Irrigation should be regular but moderate, avoiding excess water that could cause the cuttings to rot (Agronoblog, 2024). Vegetative Development phase, which extends from 60 to 90 days, cassava develops its root system and aerial parts, forming vigorous leaves and stems. It is essential to provide essential nutrients, especially nitrogen (N) and phosphorus (P), to support vegetative growth. Irrigation should be regular, especially during dry periods, and constant weed control should be maintained to avoid competition for nutrients and water (Agronoblog, 2024).

**Life cycle/Stagesc of growth**

Each phase of the cassava life cycle, from planting to harvest, requires specific management to maximize yield and root quality. During the planting and emergence stage, healthy and high-quality cuttings approximately 20-30 cm long are selected. The cuttings are planted in furrows or holes at a depth of 5-10 cm, with a spacing of 1 meter between plants and 1 meter between rows. This phase lasts between 15 and 30 days, depending on climatic conditions. Root formation and development, *i.e.*, during the next 90 to 180 days, the tuberous roots begin to develop and accumulate starch, which is the plant's main energy source. Potassium (K) becomes crucial at this stage to promote root thickening and quality. It is advisable to apply potassium-rich fertilizers and continue with adequate irrigation. Pest and disease control should be rigorous, as growing roots are vulnerable to various pathogens and pests (Agronoblog, 2024). Root maturation phase, which lasts approximately 180 to 270 days, the roots reach their optimal size and weight. The plant reduces its vegetative growth and redirects energy towards root thickening.

| | | |
|---|---|---|
|  |  |  |
| **Cutting cassava stems** | **Cuttings** | **Planting cassava stem cuttings** |
|  |  |  |
| **Young plants** | **Young plants** | **Plants** |
|  |  |  |
| **Flower buds** | **Inflorescence** | **Inflorescence** |

Continue …..

Inflorescence

Male flower

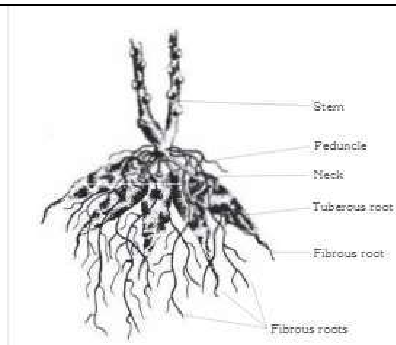
Female flower

Fruits

Fruit

Cassava fruits and seeds.

Seeds




Parts of plant

Tubers

Harvesting in field

Harvesting in field

Tuber in cross-section

**Fig. 1 : Botanical Description**

It is crucial to reduce irrigation to avoid excess moisture that could damage mature roots. Pest and disease monitoring should continue, although the need for fertilization decreases in this stage (Agronoblog, 2024). Cassava harvesting takes place between 9 and 12 months after planting, depending on the variety and climatic conditions. The optimal harvest time should be chosen when the roots have reached their ideal size and starch content. Harvesting is done manually or with specialized machinery, taking care not to damage the roots. Subsequently, the roots should be cleaned and, if necessary, cured in a dry, ventilated place before storage or processing (Agronoblog, 2024).

**Phenological Stages of Cassava (Agronoblog, 2024).**

| Phenological Stage | Duration (days) | Nutrient Recommendation (kg/ha) |
|---|---|---|
| Planting and Emergence | 15-30 | N: 40-60, P: 20-30, K: 20-30 |
| Vegetative Development | 60-90 | N: 100-150, P: 40-60, K: 60-80 |
| Root Formation and Development | 90-180 | N: 50-70, P: 30-40, K: 80-120 |
| Root Maturation | 180-270 | N: 20-30, P: 20-30, K: 40-60 |
| Harvest | 270-360 | N/A |

**Pollination and Hybridization:** Cassava is a monoecious crop – male and female flowers are separate from each other. Female flowers open first followed by male flowers (1-2 weeks after). Naturally, self- and cross-pollination occur in cassava. Before doing pollination, check if the condition is favorable. It's better if the sky is clear and there is low chance of rain for the whole day. Prepare materials (*i.e.* glassine bag, uncoated paper clip, marker). The first step is to determine female flowers that will open that day in the morning. One sure way to know that the female flower will open in the afternoon of the same day is to open one petal of an unopened female flower in the morning and check a drop of nectar on the basal part of the pistil. After selecting the female flower that is about to open in the afternoon, cover it with glassine bag and secure with a clip. In the afternoon, go back to your cassava plants. Opening of both male and female flowers usually begin from 12:00-2:00 pm and remain open for a day. Gather male flowers available or those that you intend to cross in a small bottle/container/glassine bag. Get one male flower and rub the pollen to the pistil of the female flower. Put label on the glassine bag – include the cross combination and date of crossing. Immediately cover the newly crossed male and female flowers with the labeled glassine bag and secure it with a clip. Male and female flowers are highly receptive between 1:00-5:00 pm and therefore pollination is best done during these hours. A male flower can be crossed to three female flowers. After 1-2 weeks of pollination, cover the crossed flowers with small net bag that will protect the fruit from fruit fly and catch the seeds that naturally fall off at maturity (3 months after pollination) (Agriwanderist, 2019). Pollination and hybridization is given in Fig. 2.

## GENETICS AND CYTOGENETICS

All *Manihot* species so far examined, including cassava (*Manihot esculenta*), have 2n = 36. Interspecific hybrids between cassava and its wild relatives show fair regular meiosis, and backcrossed generations exhibit high fertility. Electrophoresis shows affinity between species of different sections, as well as between some of them and cassava itself. Polyploidy has apparently contributed to the rapid speciation of this genus, while apomixis has offered a means of perpetuating new hybrid types adapted to different environments. It is assumed that cassava originated by hybridization between two wild Manihot species followed by vegetative reproduction of the hybrid (Nassar, 2000). Thirty-nine cultivars of cassava and eight related wild species of Manihot were analyzed in this work for number, morphology and size of chromosomes, prophase condensation pattern and the structure of the interphase nucleus. In four accessions, the chromosome size was measured and in some others, the number of secondary constrictions, meiotic behavior, C-band pattern, CMA/DAPI bands, nucleoli number and the location of 5S and 18S-5.8S-28S rDNA sites were also observed. All investigated accessions showed a similar karyotype with 2n = 36, small metacentric to submetacentric chromosomes. Two pairs of terminal secondary constrictions were observed in the chromosome complement of each accession except Manihot sp. 1, which presented two proximal secondary constrictions. The prophase chromosome condensation pattern was proximal and the interphase nuclei structure was areticulate to semi-reticulate. The meiosis, investigated in seven cultivars and four wild species, was regular, displaying 18 bivalents. C-banding revealed heterochromatin in 9 or 10 chromosomes. The analysis with fluorochromes frequently showed four chromosome pairs with a single CMA+ terminal or subterminal band and a few other chromosomes with DAPI+ unstable bands. Six 45S rDNA sites were revealed by FISH, which seemed to colocalize with six CMA+ bands. Only one chromosome pair presented a 5S rDNA site. The maximum nucleoli number observed per nucleus was also six. These data suggest that all Manihot species present a very similar chromosome complement (De Carvalho et al, 2002). Cassava periclinal cytochimeras, cultivars, and interspecific hybrid and polyploid types were studied in relation to embryonic, cytogenetic, and anatomical behavior. Their apical shoots, pollen grains, male and female buds, roots, stomata, and flowering period were analyzed. Chimeras exhibited increased size of L1 and L2 cells. Polyploidy led to enlargement of stomata in chimeras whereas L2 gave tetraploid chromosome configurations, tetrad irregularity, decrease of pollen viability, and increase in frequency of polyembryo sacs. The chimeric composition of tetraploids L1 and L2 and diploid L3 expressed a notable epigenetic effect seen in a marked enlargement of edible roots compared to total diploid. One of the chimeric types was accompanied by complete flowering inhibition. Pollen viability and diameter appeared to be reliable markers to determine ploidy levels (Hashimoto-Freitas and Nassar, 2013).

Cassava has 36 chromosomes, forming 18 bivalents at meiosis. However, there are cytological and sequence information supporting the paleotetraploidy nature in cassava (Fei et al, 2023). Very little is known of either cassava genetics or cassava cytogenetics. The basic chromosome number in the Euphorbiaceae family is usually 8, although this may vary between 6 and 11. About 50% of euphorbia species are polyploidy. Although cassava is frequently considered as a polyploid species, analyses conducted during diakinesis and metaphase I indicate the presence of 18 small and similar bivalents in cassava. Univalents, trivalents, and late bivalent pairings have also been observed in cassava. This plant is therefore a functional diploid, that is, 2n = 2x = 36 (Ceballos and de la Cruz, 2024). The complete and haplotype-resolved African cassava (TME204) genome has been reconstructed and made available using the Hi-C technology.


**Cassava plants**


**Flower buds**


**Weather**


**Materials required**


**Flower buds**


**Openedv flower**


**Pollination being done**


**Baging**


**Baged**


**Cassava fruit**

**Fig. 2 . Pollination and Hybridization**

The genome shows abundant novel gene loci with enriched functionality related to chromatin organization, meristem development, and cell responses. Differentially expressed transcripts of different haplotype origins were enriched for different functionality during tissue development. In each tissue, 20–30% of transcripts showed allele-specific expression differences with <2% of direction-shifting. Despite high gene synteny, the HiFi genome assembly revealed extensive chromosome rearrangements and abundant intra-genomic and inter-genomic divergent sequences, with significant structural variations mostly related to long terminal repeat retrotransposons. Although smallholders are otherwise economically inefficient producers, they are vital to productivity at particular times. Small cassava farmers are no exception. Genetic diversity is vital when productivity has declined due to pests and diseases, and smallholders tend to retain less productive but more diverse gene pools. MeFT1 (FT) is a gene producing FT proteins which affect the formation of storage roots in many plants, including this one. Alleles in cassava include *MeFT1* and *MeFT2*. *MeFT1* expression in leaves seems to not be photoperiodic, while *MeFT2* clearly is. *MeFT1* expression encourages motivation of sucrose towards the reproductive organs, as shown by experimental over expression reducing storage root accumulation (Wikipedia. 2024).

## GENETIC DIVERSITY

To our knowledge, this is the first functional map for immunity genes based on an integrative genetic map with anchored sequencing scaffolds from genome draft in cassava. It was possible to anchor almost half of the current cassava genome sequence draft to the genetic map. The map was enriched with 189 new scaffolds that increase the last version of the cassava map in 30.7 Mb. Nearly 344 Mb or 64% of the genome sequence draft is now anchored to the genetic map. On the other hand, the map was also enriched with annotated IRPs and with reported loci associated to cassava mosaic virus resistance. The presented data will allow in the future to map and associate markers with single loci or QTLs for particular traits and molecular cloning of genes controlling these traits. In addition, these data will contribute to future efforts in closing the gaps in the sequence draft and for construction of a cassava consensus genetic map. The cassava IRP repertoire, as well as their genetic and physical map position accompanied with the

SNP information will be a reference for future genetic analysis and candidate gene approaches to improve cassava resistance to their diverse biotic diseases (Soto *et al*., 2015).

Although numerous studies of diversity have been conducted in cassava, there is no comprehensive assessment of global genetic diversity. Here we draw on previous studies and breeders' knowledge to select diversity sets from the International Institute of Tropical Agriculture (IITA) and the International Center for Tropical Agriculture (CIAT) genebanks and breeders' germplasm, as well as elite germplasm and landraces from eastern, southern and central (ESC) Africa to make a global assessment of diversity in cassava, using a SNP based GoldenGate (Illumina Inc.) assay. A synthesis of results from genetic distance and ADMIXTURE analysis essentially revealed four populations (i) South American germplasm characterised by relatively higher genetic diversity with hypothetical ancestral founder genotypes from Brazil, (ii) a smaller group of African introduction germplasm which is more distantly related to all other germplasm, (iii) West Africa germplasm dominated by IITA breeding lines, containing sources of cassava mosaic disease resistance, and IITA genebank accessions from West Africa, both characterised by slightly lower diversity, and (iv) a less cohesive group of African germplasm, termed 'Other', with moderate levels of diversity and a majority of germplasm from ESC Africa. This study highlights opportunities for heterosis breeding, purging of duplicates in genebanks and the need for conservation of ESC Africa landraces (Ferguson *et al,* 2019).

Dearth of information on extent of genetic variability in cassava limits the genetic improvement of cassava genotypes in Sierra Leone. The aim of this study was to assess the genetic diversity and relationships within 102 cassava genotypes using agro-morphological and single nucleotide polymorphism markers. Morphological classification based on qualitative traits categorized the germplasm into five different groups, whereas the quantitative trait set had four groups. The SNP markers classified the germplasm into three main cluster groups. A total of seven principal components (PCs) in the qualitative and four PCs in the quantitative trait sets accounted for 79.03% and 72.30% of the total genetic variation, respectively. Significant and positive correlations were observed between average yield per plant and harvest index (r = 0.76***), number of storage roots per plant and harvest index (r = 0.33*), height at first branching and harvest index (0.26*), number of storage roots per plant and average yield per plant (r = 0.58*), height at first branching and average yield per plant (r = 0.24*), length of leaf lobe and petiole length (r = 0.38*), number of leaf lobe and petiole length (r = 0.31*), width of leaf lobe and length of leaf lobe (r = 0.36*), number of leaf lobe and length of leaf lobe (r = 0.43*), starch content and dry matter content (r = 0.99***), number of leaf lobe and root dry matter (r = 0.30*), number of leaf lobe and starch content (r = 0.28*), and height at first branching and plant height (r = 0.45**). Findings are useful for conservation, management, short term recommendation for release and genetic improvement of the crop (Karim *et al*, 2020).

Genetic diversity is of paramount importance in crop improvement through breeding. The extent and nature of genetic variation existing within cassava landraces and cultivars from selected African countries have been assessed using molecular markers. These studies have revealed genetic differentiation between African and South American germplasm, as well as differentiation between cassava landraces within Africa. Those from East, South, and Central Africa are somewhat differentiated from those from West Africa. The narrow genetic base of African cassava breeding lines is attributable to intense selection pressure for CMD resistance with recurrent selection using few parents and the clonal nature of the crop. Slightly higher genetic diversity has been reported in landraces in comparison to elite accessions, which is typical of most crops. It is likely that the genepool of pre-breeding germplasm will become more diverse as breeders begin to incorporate variation that responds better to consumer preferences (Mbanjo *et al*., 2020). This paper highlights genomic tools and resources available in cassava. The paper also provides a glimpse of how these resources have been used to screen and understand the pattern of cassava genetic diversity on the continent. Here, we reviewed the approaches currently used for phenotyping cassava traits, highlighting the methodologies used to link genotypic and phenotypic information, dissect the genetics architecture of key cassava traits, and identify quantitative trait loci/markers significantly associated with those traits. Additionally, we examined how knowledge acquired is utilized to contribute to crop improvement. We explored major approaches applied in the field of molecular breeding for cassava, their promises, and limitations. We also examined the role of national agricultural research systems as key partners for sustainable cassava production (Mbanjo *et al.,* 2020).

Genetic improvement begins with the collection and evaluation of diverse genetic resources. Various evolutionary forces such as mutations, migration, hybridization, and polyploidization are responsible for creating variation in plants. In cassava, it is believed that the wide range of genetic diversity was generated through natural and artificial hybridization between the wild *Manihot* spp. and cultivated cassava or through apomixes (Amelewor and Bairu, 2022). Currently, several national and international research institutes hold large collections of cassava germplasm. The International Centre for Tropical agriculture (CIAT) in Colombia comprises more than 6000 cassava accessions collected mainly (97%) from Latin America and of which 30% of the accessions are of Brazilian origin. The International Institute for Tropical Agriculture (IITA) in Nigeria, on the other hand, consists of more than 2000 genotypes largely of West African origin. Understanding the nature and magnitude of genetic variation present within and among individuals, populations, species, and gene pools is crucial for the efficient management of genetic resources. Genetic diversity is assessed with morphological, biochemical, and/or molecular markers. However, the environment and genotype by environment interaction effects limit the effectiveness of genetic diversity studies using morphological and biochemical markers. Molecular markers permit the detection of genetic differences among closely related and wild species (Amelewor and Bairu, 2022). The success of genetic improvement of any trait depends on the nature of variability present within the trait. In modern cassava breeding, a source population with high frequencies of alleles associated with desirable characters are developed through collection or hybridization of genotypes derived from selected elite clones. New improved cultivars can be developed following selection of superior clones from segregating populations (Amelewor and Bairu, 2022).

Modern agricultural practices and the destruction of native cassava habitats in the centers of diversity cause significant erosion of cassava genetic resource. Therefore, collection and conservation of cassava germplasm is of paramount importance to sustained successes in cassava breeding. Great efforts have been put forth to collect and conserve cassava germplasm. Table 1 lists the number of accessions maintained at each location. The international institutes, the Centro Internacional de Agricultura Tropical (CIAT), Colombia, and the International Institute for Tropical Agriculture (IITA), Nigeria, both of which hold the UN mandate for cassava maintain a large number of accessions (Fei *et al,* 2023).

Thirty cassava accessions, including released and pre-release varieties in India were selected for morphological, statistical and molecular analysis to evaluate their genetic divergence. Based on ANOVA (Analysis of Variance), significant differences were observed in thirty genotypes for the fifteen characters used in the study. Most of the characters such as plant height, stem weight plant$^{-1}$, number of leaves plant$^{-1}$ and mean weight of tuber exhibited high GCV and PCV along with a positive correlation to tuber yield plant$^{-1}$. Path analysis showed that stem weight plant$^{-1}$, number of tubers plant$^{-1}$, number of leaves plant$^{-1}$, leaf dry matter content and number of nodes plant$^{-1}$ directly affected tuber yield plant$^{-1}$. The genotypes were then grouped into nine clusters following Mahalanobis' $D^2$ statistics with clusters IV and VIII recording the maximum inter-cluster distance, which gave an idea about the diversity prevailing among them. PCA analysis showed that stem girth, number of nodes and tuber yield plant$^{-1}$ accounted for greater variability among the genotypes. Molecular analysis using SSR markers showed polymorphism for eighteen markers and molecular dendrogram clustering grouped the genotypes into three principal clusters with different subclusters. Overall, the study highlights the genomic diversity of cassava accessions and provides valuable insights into their characteristics and yield potential (Sivan *et al.,* 2023).

## BREEDING

Gene Banks

**Field genebanks:** Cassava plants representing each accession are grown and maintained in the field. As is practiced at IITA, eleven plants of each accession are grown on a 2.5m row plot with a 25cm space between plants and 50cm space between rows. Field genebanks require a large amount of field space and germplasm may be lost due to various biotic and abiotic stresses (Fei *et al*, 2023).

**Seed genebank:** Seed of each accession are maintained in controlled environment with low temperatures and humidity. It has been reported that cassava seeds remain viable after 14 years of hermetic storage at -20°C with 6% moisture content in the seed. As is practiced at IITA, seeds representing each accession are harvested in bulk from all plants of an accession and are therefore heterogeneous (Fei *et al*, 2023).

**Breeding Objectives**

- Developing high-yielding cassava cultivars remains the highest priority of most, if not all cassava breeding programs. Root yield in cassava is, however, a complex trait and is affected by both genetics, environment, and their interactions. Cassava plants with an intermediate branching height have been shown to be highly correlated with high yield. Similarly, plants with good leaf retention (longer leaf life) are also found to be correlated with high root yield (Fei *et al*, 2023).
- Root quality is very important as it affects consumer acceptance and successful adoption of a cultivar. Cultivars with highly reduced cyanogenic glucosides and increased dry matter in the roots are desired. Cassava roots are naturally low in protein, therefore cultivars with enhanced protein content are desirable if they are used for animal feed. Cultivars with altered starch content and composition may be developed for specialty use (Fei *et al*, 2023).
- Cassava production is constrained by many biotic stresses including some of the most devastating viral diseases such as cassava mosaic disease and cassava brown streak disease that can cause significant yield loss. Bacterial diseases such as cassava bacterial blight and root rot can also cause damages. Developing cassava germplasm with resistance to a number of insects including cassava mites, mealybugs, and whiteflies which are responsible for transmitting the devastating CMD is of great importance (Fei *et al*, 2023).
- The shelf life of cassava roots is notoriously short, often within 2 days after harvest. This post-harvest deterioration of cassava roots is manifested by internal discoloration which causes the immediate loss of marketability. Developing cassava cultivars that are resistant to this post-harvest physiological deterioration is therefore highly desirable (Fei *et al*, 2023).

**Principles of Cassava Cultivar Development:** Cassava is primarily cross-pollinated, therefore individual plants are highly heterozygous. Because cassava can be easily propagated by stem cuttings, improved cassava cultivars are primarily clonal cultivars that are multiplied by stem cuttings for distribution (Fei *et al*, 2023). Therefore, the principle of developing clonally propagated cultivars for other crops also applies to cassava. Briefly, large segregating populations are first created from which initial seedling screening is performed. Plants selected from the initial screening are then evaluated in subsequent replicated, multi-location trials that would eventually produce one or more superior clones possessing desirable traits (Fei *et al*, 2023). The following flowchart describes the general aspects of a cassava breeding procedure (Fei *et al*, 2023):

- Population development
- Seedling evaluation and selection
- Clonal evaluation and selection
- Preliminary yield trial and selection
- Advanced yield trials and selection
- Regional trials

While the size of the initial population is large (for example, 50,000 seedlings), the number of entries is drastically reduced following each step of selection, and at the end of the regional trial, only one or a few clones may endure the rigorous selection process and are released as new cultivars (Fei *et al*, 2023).

**Cassava Hybridization Techniques:** To determine if a female flower is about to open, a reliable method by which a petal of an unopened female flower is peeled back, if a drop of nectar is observed at the base of the pistil, the flower will open in the afternoon of the same day. Female flowers ready to be pollinated are then covered with a large (20 cm x 25 cm) cloth bag to avoid stray pollen. Emasculation is generally not necessary because male flowers on the same inflorescence will not open until 1 to 2 weeks later when the female flowers either developed into fruits or have died. Between noon and 2 pm in the afternoon, freshly open male flowers are collected by glass bottle or other suitable devices and pollination can be performed immediately. A single male flower can pollinate up to three female flowers. Pollination performed after 5 pm will not be as effective. Pollinated female flowers can be left uncovered to promote seed development with minimal risk of hybridization by stray pollen. However covering of the pollinated flowers with a small cloth bag is needed 1 or 2 weeks after the pollination in order to collect seeds (Fei *et al*, 2023).

**Breeding for Yield and Quality Related Traits: Starch Content**: Starch has been the subject of intensive research over many decades. Cassava is the second most important source of starch worldwide, after maize, and the most traded one. The average starch content of cassava is 84.5% on a dry weight basis and the average amylose content is 20.7%, ranging between 15.2 and 26.5%. Cassava starch is the cheapest and the most preferred known form of starch with many positive characteristics such as high paste clarity, relatively good stability to retrogradation and swelling capacity, low protein complex, and good texture. Novel starch properties such as amylose-free and high-amylose starch are of interest to the cassava community (Amelewor and Bairu, 2022). South Africa is a highly industrialized country and starch is widely used by the food, alcohol, textile, pharmaceutical, cosmetic, adhesive, paper, and plywood industries. The Republic is Africa's largest producer of starch and exports starch to neighboring countries. The starch industries in South Africa have been producing starch mainly (95%) from maize. There is a huge competition among industries utilizing maize products and other uses. Hence, the starch industry is not able to satisfy the local demands. Hence, South Africa has been importing thousands of tons of starch from Southeast Asia annually. Exploitation of cassava as a source of starch will provide an alternative to the maize industry. Producing starch from cassava locally will satisfy local starch demands, avoid competition among staple food commodities, relieve the country's economy from foreign currency strains, and reduce import volumes (Amelewor and Bairu, 2022).

**Dry Matter Content**: Dry matter content is an important character for the acceptance of cassava by producer, consumer, and processor. It is considered as the economic or true biological yield, which is controlled by polygenes. The proportion of dry matter in cassava storage roots ranges from 17 to 47%, with the majority of the accessions lying between 20% and 40% and values above 30% are considered to be high. Dry matter content is highly influenced by a number of genetic and environmental factors such as age of the crop, efficiency of the canopy to trap sunlight, season, and location effects.. The longer the plants stay on the field, the more dry matter and starch is accumulated. It was reported that yields of fresh and dry roots as well as starch increased progressively from 8 to 18 months after planting (MAP) (Amelewor and Bairu, 2022).It was reported that, on average, nearly 90% of cassava root dry weight is carbohydrate, 4% crude fiber, 3% ash, 2% crude protein, and 1% fat. Dry matter partitioning into different plant parts varies with the growth cycle of the plant. During the early growth stages of the plant, more dry matter is accumulated in the leaves than in the stems and storage roots. However, at 4 MAP about 50–60% of the total dry matter is accumulated in the storage roots (Amelewor and Bairu, 2022). Total dry weight of a cassava plant is positively associated with dry weight of the storage roots, suggesting that both traits could be improved simultaneously. However, dry matter content is not associated with fresh root yield. Under tropical conditions, maximum rate of dry matter accumulation was detected at 3–5 MAP. while at high attitudes maximum rate was observed at 7 MAP. Although the rate of dry matter accumulation varies with the genotypes and growing conditions, it was suggested that selection for dry matter content should not be performed before 4 MAP (Amelewor and Bairu, 2022).

*Early Bulking***:** Early bulking is an important trait in cassava, referring to the thickening of storage roots as they fill with assimilates after the plant satisfies its need for vegetative growth. Early bulkers are those cultivars that are harvestable within 7–8 MAP. Breeders have been used early bulking as a drought tolerance mechanism. Various researchers have different opinions on the onset and rate of bulking (Amelewor and Bairu, 2022). Cassava, being a tropical crop, prefers humid-warm climates with temperature ranges of 25–29 °C and an altitude below 1500 m. Cassava is highly sensitive to low temperatures below 18 °C. Low temperature causes delayed sprouting of stem cuttings, reduced leaf expansion, low biomass accumulation, and decreased storage root yield. In South Africa, the growing season is characterized by a hot rainy summer followed by a cold and dry winter. Frost is a major obstacle for cassava production and propagation in some parts of South Africa (Amelewor and Bairu, 2022). Therefore, early bulking cultivars, that fit into the growing season (i.e., matures within 7–9 MAP), or cold-tolerant cultivars that can grow in a prolonged growth period are in demand. Early maturing cassava genotypes that can escape the cold winter should be the focus of cassava breeding in South Africa (Amelewor and Bairu, 2022).

**Cyanogenic Content:** Cyanogenic glycosides (CN) are a group of chemical compounds that produced hydrogen cyanide following enzymatic breakdown. There are at least 25 cyanogenic glycosides known to be found in the edible parts of plants. Many species produce and sequester cyanogenic glycosides including cassava, sorghum, almonds, lima beans, flax, and white clover. In plants, glycoside hydrolysis occurs when the plant tissues have been disrupted by herbivores, fungal attack, or mechanical damage. Although many explanations have been given on the importance of CN in plants, the most probable physiological role of CN is defense against herbivores, pathogens, competitors, and theft. In support of this view, bitter cassava genotypes exhibited greater tolerance to CMD and drought than sweet cassava (Amelewor and Bairu, 2022). The predominant cyanogenic compounds in cassava roots and leaves are linamarin (95%) and lotaustralin (5%). Depending on the genetic, physiological, climatic, and edaphic factors, the normal range of cyanogenic glycoside content in cassava ranged from 1 to 1300 mg per kg of dry weight. However, some reports indicated that the total cyanogenic content of the roots was not correlated with the content in the leaves and stems of the same plant. The levels of cyanogenic glycosides in cassava roots are generally lower than that in the leaves and stems. It has been reported that cassava roots contain a cyanide content of 10–500 mg per kg of dry matter, while the leaves contain 53–1300 mg per kg of dry matter (Amelewor and Bairu, 2022). Cassava cultivars have been classified biochemically using cyanogenic glucoside content as bitter and sweet depending on the presence or absence of toxic levels of cyanogenic glucosides, respectively. The bitter cultivars are characterized by their high cyanogenic content (100–400 mg per kilogram of fresh weight of roots) distributed throughout the storage roots, whereas those cultivars with very low cyanogenic content (15–50 mg per kilogram of fresh weight of roots) mainly confined in the peel are termed as sweet varieties. The utilization of cassava as food and feed is limited by the toxic level of cyanogen. Consumption of raw or inadequately processed cassava can lead to chronic and acute health problems resulting from cyanide poisoning. The World Health Organization (WHO) recommended 10 ppm or 10 mg hydrogen cyanide per kg of cassava flour as a safe level. Sweet cassava roots can be eaten by peeling and cooking, whereas bitter varieties require more extensive processing such as peeling, washing, grating, fermenting, drying, or frying. Efforts have been made on breeding and selection of low-cyanogen varieties, development of low-cyanogen mutants through mutagenesis, and genetic engineering (Amelewor and Bairu, 2022).

**Breeding for Biotic Stresses (Amelewor and Bairu, 2022).**
Cassava Mosaic Disease (CMD)

**Cassava Brown Streak Disease (CBSD)**

**Application of Biotechnology**

Traditional plant breeding is a very long and imprecise process and it could take more than a decade to release an improved new cultivar. Genetic transformation, however can introduce a trait very efficiently and rapidly. Furthermore it can break the reproductive barrier and transfer traits from unrelated species to cassava. Because cassava is a vegetatively propagated species, traits introduced into an existing elite cultivar or a farmer-favored landrace can be “fixed” immediately without the need of inbreeding or backcross as is the case in sexually propagated species. Successful genetic transformation has been accomplished in cassava using either Agrobacterium or particle bombardment. The key to the success relies on an efficient plant regeneration protocol. The current standard practice is to use the friable embryogenic callus (FEC) derived from immature leaf explants cultured in vitro for gene transfer. The potential of using a transgenic approach to produce novel cassava germplasm has been demonstrated in transgenic lines with insect and disease resistance, herbicide tolerance, altered starch content and increased protein level as well as reduced cyanogenic content in cassava storage roots. Another noted example is the biofortified cassava generated by the BioCassava Plus (BC+) program supported by the Bill and Melinda Gates Foundation. These biofortified cassava varieties demonstrated the potential of developing cassava as a more nutritionally complete crop with increased zinc, iron, proteins and vitamin A (Fei *et al*, 2023).

**Genomic Resources of Cassava:** Cassava is a naturally diploid species (2n = 36) with a genome size of 770 Mbp. Although most of the species studied contain 36 chromosomes and are regarded as diploids (2n), irregular pairing at meiosis and spontaneous polyploidization (e.g., triploids (3n) and tetraploids (4n)) have been reported in both wild and domesticated cassava. Likewise, the presence of three nucleolar chromosomes has been reported in cassava, which is high for true diploids, suggesting that Manihot species are probably segmental allotetraploids with a basic chromosome number x = 9 (Amelewor and Bairu, 2022).

**Major accomplishments in cassava breeding:** Notable is the consistent increase in production and harvested area despite the low yields in Africa compared to Asia and Latin America/Caribbean. Thus there is potential for even greater increases in Africa with the increased availability of improve cultivars (Fei *et al*, 2023).

**Post-Harvest Physiological Deterioration (PPD):** PPD is a major constraint for the production, development, expansion, and exploitation of cassava as an industrial crop in many parts of the world.. It is the outcome of intricate interactions of simultaneously occurring cellular functions in the harvested cassava roots and results in considerable quantitative and qualitative post-harvest losses of the fresh cassava roots. However, environmental factors such as age of the plant, root conditions during harvest and thereafter, and storage conditions significantly influence the development and effects of PPD (Amelewor and Bairu, 2022).

**Preparation of bitter cassava:** A safe processing method known as the "wetting method" is to mix the cassava flour with water into a thick paste, spread it in a thin layer over a basket and then let it stand for five hours at 30 °C in the shade. In that time, about 83% of the cyanogenic glycosides are broken down by linamarase; the resulting hydrogen cyanide escapes to the atmosphere, making the flour safe for consumption the same evening. The traditional method used in West Africa is to peel the roots and put them into water for three days to ferment. The roots are then dried or cooked. In Nigeria and several other west African countries, including Ghana, Cameroon, Benin, Togo, Ivory Coast, and Burkina Faso, they are usually grated and lightly fried in palm oil to preserve them. The result is a foodstuff called garri. Fermentation is also used in other places such as Indonesia, such as Tapai. The fermentation process also reduces the level of antinutrients, making the cassava a more nutritious food.[95] The reliance on cassava as a food source and the resulting exposure to the goitrogenic effects of thiocyanate has been responsible for the endemic goiters seen in the Akoko area of southwestern Nigeria (Wikipedia. 2024). A traditional method used by the Lucayans to detoxify cassava is by peeling, grinding, and mashing; filtering the mash through a basket tube to remove the hydrogen cyanide; and drying and sieving the mash for flour. The poisonous filtrate water was boiled to release the hydrogen cyanide, and used as a base for stews (Wikipedia. 2024). Bioengineering has been applied to grow cassava with lower cyanogenic glycosides combined with fortification of vitamin A, iron and protein to improve the nutrition of people in sub-Saharan Africa. In Guyana the traditional cassareep is made from bitter cassava juice. The juice is boiled until it is reduced by half in volume, to the consistency of molasses and flavored with spices—including cloves, cinnamon, salt, sugar, and cayenne pepper. Traditionally, cassareep was boiled in a soft pot, the actual "pepper pot", which would absorb the flavors and also impart them (even if dry) to foods such as rice and chicken cooked in it. The poisonous but volatile hydrogen cyanide is evaporated by heating. Nevertheless, improperly cooked cassava has been blamed for a number of deaths. Amerindians from Guyana reportedly made an antidote by steeping chili peppers in rum. The natives of Guyana traditionally brought the product to town in bottles, and it is available on the US market in bottled form (Wikipedia. 2024).

## Varieties

Below is a summary of such achievements and those widely used today for food and industrial purposes (Cassavaindia, 2024):

| Name of Variety | Description | Duration (months) | Yield (t/ha) |
|---|---|---|---|
| H-97 | A hybrid between a local variety and a Brazilian selection. It has conical, short roots. | 10 | 25-35 |
| H-165 | A hybrid between two local cultivars. The roots are relatively short and conical, | 8-9 | 33-38 |
| H-226 | A hybrid between a local cultivar and the Malayan introduction, M4. H-226 has a high yield under irrigated cultivation in Tamil Nadu. | 10 | 30-35 |
| Sree Visakham | A hybrid between a local cultivar and a Madagascar variety. It has compact roots, which have yellow flesh due to a high carotene content (466 IU/100 g) | 10 | 35-38 |
| Sree Sahya | A multiple hybrid involving five parents, two of which are exotic and three indigenous. The roots are long-necked, | 10-11 | 35-40 |
| Sree Prakash | Is an indigenous selection. The plants are relatively short with high leaf retention. | 7-8 | 35-50 |
| Sree Jaya | A selection from indigenous germplasm. The plants are medium in height, yielding conical roots with white flesh | 6 | 26-30 |
| Sree Harsha | Is the first triploid variety of cassava, released in 1996 (Sreekumari et al., 1999). It is a hybrid between a diploid selection and induced tetraploid of the released variety Sree Sahya. The plants are short, vigorous and non-branching or top-branching. The leaves are broad, thick and dark green in color. Its roots are very compact. Crop duration is ten months, but because of its early bulking nature it can be harvested as early as the 7th month without any yield loss or starch reduction in the roots. Sree Harsha has recorded the highest starch content of 39.1% among the released cassava varieties. | 7-10 | 35-40 |
| Nidhi | A clonal selection suited to areas of sandy loam soils of central Kerala | 6 | 25 |
| KMC-1 | A clonal selection suitable for intercropping in coconut gardens of central Kerala. | 6 | 30.5 |
| CO-1 | A clonal selection from a local variety | 8-9 | 30 |
| CO-2 | A clonal selection from an open-pollinated seedling progeny of a local type. It has compact roots. | 8-9 | 35 |
| CO-3 | A clonal selection from open-pollinated seedlings of Nigerian origin. Duration under irrigation is 42.6 t/ha and rainfed is 27.3. | 8 | 27 – 42 |
| MVD-1 | A clonal selection exhibiting field tolerance to CMD | 9 | 34.5 |

The best cassava varieties are those that have the quality required by consumers, processors, and industries. Some of these qualities include early maturity, good yield, long storability in the soil, and tolerance to major pests and diseases (Wikifarmer, 2024).

Approved cassava varieties by the Nigerian government (Wikifarmer, 2024).

- The most popular variety is TME 419
- Dixon, formally known as 0581 (TMS-9800581)
- Farmer's Pride, formally known as 1632 (TMS-981632)
- Fine Face, formally known as 0505 (TMS-980505)
- Sunshine, formally known as 0593 (TMS-070593)
- Ayaya formerly CR36-5 OR 365 (CR36-5)

**Newly developed varieties (Wikifarmer, 2024).**

- Game-Changer has high and stable starch content, which is desired by industrial processors for flour, starch, and ethanol production on a large scale.
- Hope has excellent garri (or gari) and fufu quality to address the processed food market in Nigeria.
- Obasanjo-2 also exhibits similar produce to the Hope variety.
- Baba-70 also exhibit similar attribute like Game-changer in providing excellent garri and fufu quality to address the processed food market.
- Poundable is the first fresh market variety released in Nigeria.

## CULTIVATION

**Propagation Methods:** Cassava can be propagated by either seed or stem cuttings (stakes). Because cassava plants are highly heterozygous, seed propagation will result in highly heterogeneous offspring that no longer possess the desirable traits of the seed parent. Consequently, cassava propagation is done mostly through stem cuttings (Fei *et al,* 2023). Multiplication rate is one of the determining factors that affect whether a new improved cultivar is successfully adopted or not. After one year, a typical mature cassava plant will produce 10-30 stakes sized at about 25cm. Reducing the stake size to include only two nodes or one per stake will likely produce 100 or 200 stakes from a single plant per year, resulting a multiplication rate of 100 or 200. Such multiplication rates, although high may still not be sufficiently rapid to produce a large quantity of stakes in a short period of time to meet the consumer demand. Even higher multiplication rates have been achieved by growing 2-node stakes in high density in moist chambers and continuously removing sprouting shoots of 15-20cm long for rooting in boiled water. Rooted plantlets are transferred to soil and after a brief period of hardening are transplanted to the field for production. Such a system can produce a multiplication rate of 36,000 (Fei *et al*, 2023).

**Cuttings:** Cassava is propagated from stem cuttings as the tubers do not produce buds. Stem cuttings should only be taken from plants which are free from disease, are at least 10 months old and have borne tubers. The cuttings should be taken from hardened stems leaving at least 30 cm of stem intact in the ground. The stem can be severed using a sharp knife, secateurs or saw and each cutting should have 1-2 nodes and be approximately 20 cm long (Anonymous, 2024).

**Presprouting:** It is a good idea to dip the stem cuttings in an appropriate fungicide prior to planting to help prevent the development of diseases. The cuttings can then either be planted directly into a nursery bed or presprouted in trays or polyethylene bags. To presprout the stems, plant in a cell tray or bag which is filled with good quality soil. Plant one stem in each cell or bag by pushing it into the soil in the direction in which it was growing on the mother plant (oldest part of stem first). The trays should be kept in partial shade until the stems begin to sprout. If planting stem cuttings in a nursery bed (best for cuttings taken from higher up the stems where the wood is not mature), select a site with good quality soil in partial shade and prepare a bed at least 1 m wide. The stems can be planted horizontally in a nursery bed and this encourages the growth of multiple stems. Space the cuttings 10 cm x 10 cm grid. Stem cutting should be watered immediately after planting and on a regular basis thereafter. Aim to keep the soil moist but not wet. Stems should begin to sprout 7-10 days after planting (Anonymous, 2024).

**Pruning:** Pruning is a practice in horticulture that involves selecting and removing certain parts of a plant. These parts may include branches, buds, leaves or roots. The main goal of pruning is to enhance the healthy growth and development of cassava plants. This can be achieved by improving the plant's structure which may result in the formation of new stems. The timing for cassava pruning depends on the farmers' objective regarding the desired outcome of the cassava crop.

Pruning cassava 12 months after planting is an essential strategy that can improve the root quality of cassava at harvest. Also, pruning can create entries for pests and diseases to fester.

The yield of cassava can be reduced when pruned. As such, the pruning of cassava can be significantly affected by weather conditions. This means pruning cassava leaves in the rainy season may result in the health and stability of cassava plants compared to the dry season where there is limited rainfall. It is advisable that the pruning of cassava should be done 4 weeks before harvesting (Wikifarmer, 2024b)

**Benefits of pruning cassava (Wikifarmer, 2024b):**

- New planting materials (stems) are easily available before the harvest season.
- Pruning cassava can make intercropping of cassava with other crops.
- The pruning of cassava leaves is used to feed ruminant animals in Nigeria.
- Pruning of cassava can create an avenue where light intercepting cultivars are reduced, and this benefits plants in the late season.
- The pruning of cassava greatly favours the mechanical harvesting of cassava roots.
- Cassava plants that are pruned before harvesting takes place can serve as a strategy to extend cassava shelf-life. That is to say that susceptibility to postharvest physiological deterioration (PPD) is reduced and limited.

**Drawbacks of pruning of cassava (Wikifarmer, 2024b):**

- The starch components in pruned cassava are low and may not be used for commercial purposes where starch is required as a raw material. This is because pruning interrupts the physiological processes in root development in plants. This may lead to a delay in attaining the maturity of cassava crops.
- Pruning reduces the original value of cultivars.
- Pruning results in low productivity of tuberous roots, low aerial parts weight of plants and reduction of dry matter.
- Regular pruning of cassava leaves may hinder the growth of the cassava plant; it may not grow beyond 1.20 m tall
- Pruning cassava also increases the cooking time of tubers when compared to non-pruned plants.

**Pruning methods of cassava:** Cutback: Cutback is the process whereby all shoots and branches of cassava are pruned. This pruning method serves as means to generate seedlings for early planting before harvesting is done. This pruning technique usually makes planting materials easily available. Cuttings with 6 to 8 visible leaves are usually collected for planting at the end of September (Wikifarmer, 2024b). Debranching: Debranching is the process of pruning all the branches of cassava plants except the stem is pruned. Debranching as a technique may affect the canopy structure because stem and leaf growths decrease. Farmers applied this method of pruning when they want to create an easy pathway for a smooth grazing experience for ruminant aminals. Debranching shortens cassava plants. Cassava leaves are a good source of food for goats. Since ruminant animals may damage tall cassava plants as they struggle for the leaves for food. Farmers apply this method of pruning when they still needed their plants to continue growing (Wikifarmer, 2024b)

**Cultivation:** Optimal conditions for cassava cultivation are: mean annual temperatures between 20 and 29 °C, annual precipitation between 1,000 and 2,500 mm, and an annual growth period of no less than 240 days. Cassava is propagated by cutting the stem into sections of approximately 15 cm, these being planted prior to the wet season. Cassava growth is favorable under temperatures ranging from 25 to 29 °C, but it can tolerate temperatures as low as 12 °C and as high as 40 °C. These conditions are found, among other places, in the northern part of the Gulf Coastal Plain in Mexico. In this part of Mexico the following soil types have been shown to be good for cassava cultivation: phaeozem, regosol, arenosol, andosol and luvisol (Wikipedia. 2024).

Cassava grows best on light sandy loams or on loamy sands which are moist, fertile and deep. It grows well on soils ranging in texture from the sands to the clays and on soils of relatively low fertility. Cassava can produce an economic crop on soils so depleted by repeated cultivation that they have become unsuitable for other crops. On very rich soils the plant may produce stems and leaves at the expense of roots. Cassava will grow on a wide range of soils, provided the soil texture is friable enough to allow the development of the tubers. When cassava is grown as the first crop in forest land no further preparation is required than the clearing of the forest growth. When it is grown after other crops it often can be planted without further preparation of the soil, once the preceding crop has been harvested or the soil has been plowed two or three times until free from grass and other plants **(**Moore and Lawrence, 2024**).** Cassava is frequently cultivated as a temporary shade plant in young plantations of cocoa, coffee, rubber or oil palm. When cultivated as a temporary shade plant, no special attention is given to the cassava plant. When grown alone, the plants require little maintenance after planting. Irrigation may be required if there is no rain, and hoeing of the earth helps preserve the subsoil humidity, especially in dry sandy soils. The chief problem is weed control which may be desirable to weed the crop two or three times until the plants are well developed and their shade prevents the growth of weeds. In moist soil, sprouting takes place within the first week after planting. Within a month of the beginning of planting, the substitution of new cuttings to replace those that did not sprout is still possible. Cassava is grown mainly as a cash crop and farmers may for ten years or more grow cassava on the same land. However, if the price of cassava roots drops, the farmers may shift to another crop (*e.g*., sugarcane, maize or sorghum) until cassava again becomes the more profitable crop. No fertilization is required when the land is freshly cleared or when there is enough land to enable grower to substitute new land for old when yields fall. Like all rapidly growing plants yielding carbohydrates, cassava has high nutrient requirements and exhausts the soil very rapidly. When cassava is grown on the land for a number of years in succession or in rotation the soil nutrients are reduced and must therefore be returned to the soil by fertilization. Large commercial farmers replaced the nutrients lost by applying artificial fertilizers that are usually too costly for the small farmer. Small farmers replace the nutrient loss by using different kinds of organic manures, such as cattle or duck manure or garbage to replace the nutrients taken from the soil **(**Moore and Lawrence, 2024). In most of the tropical world cassava is grown on small plots; however, in some countries (*e.g*., Mexico. Brazil and Nigeria) large plantations have been established. The degree of mechanization depends on the amount of land, available labor in the area and general policy regarding the use of manual labor. The use of machinery for land preparation is preferable to manual labor to ensure the best possible seed bed for tuber development. Subsequent operations of planting, weeding, topping and harvesting can be done by hand as well as by machinery (Moore and Lawrence, 2024). There are no established mechanical means used for planting. Because machine planting cannot be made possible without furrows and ridges, a flat field is thus recommended for machine planting. Here in Nigeria, planting by hand is the most popular type of planting cassava cuttings. Though mechanical planters are used to propagate cassava cuttings horizontally, this mode of planting has not been shown to produce maximum cassava yield compared to planting by hand. Before planting the cassava stem in the soil, the soil must be loose enough for planting. Stem cuttings can be planted not more than 5cm in depth. This is because when the stem cuttings are planted deeper in the soil, it causes it to swell, and it may result in poor yield (Wikifarmer, 2024a). The spacing of cassava is also essential in ensuring optimal yield production. The plant density and spacing depend largely on the cassava variety. For instance, cassava that exhibits branching requires 1m x 1m for the best tuber yield. Non-branching cassava plants require 0.75 m x 0.75 m per square metre. Overall, this gives 10,000 plants per hectare. The panting density that is required for the multiplication of stems and not for the production of roots, 0.5 m x 0.5 m, can be used (Wikifarmer, 2024a).

## Harvesting

There is no mature stage for cassava; because plants are ready for harvest as soon as there are storage roots large enough to meet the requirements of the consumer. Under the most favorable conditions, yields of fresh roots can reach 90 t/ha while average world yields from mostly subsistence agricultural systems average 10 t/ha. Typically harvesting can begin as soon as eight months after planting. In the tropics, plants can remain un-harvested for more than one growing season, allowing the storage roots to enlarge further. However, as the roots age and enlarge, the central portion becomes woody and inedible (Moore and Lawrence, 2024). Maturity differs from one variety to another, but for food the tubers can be harvested at almost any age below 12 months. From the standpoint of maximum starch production, the optimum age for harvest is 1820 months. During this growth period both root and starch production increase rapidly to their maximum value, after which root production decreases slowly and starch production much more rapidly on account of the declining starch content of the tubers. If the roots are left in the ground, starch content increases with age until, at a certain point; lignifications takes place, causing the roots to become tough and woody, so that they are harder to prepare for consumption and other uses. Harvesting of cassava can be done throughout the year when the roots reach maturity. In regions with seasonal rains, harvesting is usually done in the dry season, during the dormant period of the plant; where rain prevails all year round, cassava is harvested throughout the year. Harvesting is still generally a manual operation, although equipment to facilitate this operation is being considered. The day before harvest, the plants are "topped" the stalks are cut off 40-60 cm above ground by hand, machete or machine and piled at the side of the field. This length of stalk is left as a handle for pulling (Moore and Lawrence, 2024). The harvesting of cassava is becoming one of the serious bottlenecks bewildering the cassava production value chain. Harvesting is critical in the cassava production value chain. Cassava needs approximately maximum 9-12 months to mature. This depends on the variety. Early-maturing varieties are harvested 6-7 months after planting, while late-maturing varieties can be harvested after 12 months. Every fully grown cassava tuber may weigh 1 or 2 kilograms, depending on the variety. Once the cassava tubers are lifted from the ground, they cannot be kept for long before they begin to get spoiled. One of the main signs used to determine the maturity of cassava is that the leaves start turning yellow and dry. At that moment, the cassava crops are likely to be mature enough for the roots to be harvested. Cassava is harvested traditionally by hand lifting the lower part of the stem. This can be done by hand pulling the roots out of the ground and removing the cassava tuber from the base of the stem. There are various harvesting methods for cassava (manual and mechanized harvesting methods). The manual method of harvesting cassava is the most popular in Nigeria (Wikifarmer, 2024c).

Manual harvesting of cassava involves holding the stem and gently pulling the roots out of the ground. A manual hand lifter can also be used to lift the tubers. Manual harvesting is both labor- and cost-intensive and associated with drudgery and great root damage, especially under arid soil conditions. Manual harvesting requires skill and patience to minimize harmful impact on the tubers. Manual harvesting increases the total cost of production. This is because more farmhands are usually required to harvest to meet industrial and local demands, leading to increased cassava prices on the market. For this kind of harvesting method to be successful, the soil used to grow the cassava plants must be considered. Manual harvesting is much easier on wet loamy soil than on dry soil (Wikifarmer, 2024c).

**Handling and storage:** Cassava deteriorates after harvest, when the tubers are first cut. The healing mechanism produces coumaric acid, which oxidizes and blackens the tubers, making them inedible after a few days. This deterioration is related to the accumulation of reactive oxygen species initiated by cyanide release during mechanical harvesting. Cassava shelf life may be increased up to three weeks by overexpressing a cyanide-insensitive alternative oxidase, which suppressed ROS by 10-fold. Post-harvest deterioration is a major obstacle to the export of cassava. Fresh cassava can be preserved like potato, using thiabendazole or bleach as a fungicide, then wrapping in plastic, freezing, or applying a wax coating. While alternative methods for controlling post-harvest deterioration have been proposed, such as preventing reactive oxygen species effects by using plastic bags during storage and transport, coating the roots with wax, or freezing roots, such strategies have proved to be economically or technically impractical, leading to breeding of cassava varieties with improved durability after harvest, achieved by different mechanisms.[57][58] One approach used gamma rays to try to silence a gene involved in triggering deterioration; another strategy selected for plentiful carotenoids, antioxidants which may help to reduce oxidization after harvest (Wikipedia. 2024).

**Uses:** Cassava is a good source of dietary fibre as well as vitamin C, thiamin, folic acid, manganese, and potassium. The tubers have a mild nutty taste and are commonly eaten as root vegetables in stews or as side dishes. Food items such as the gelatinous *fufu* of West Africa and the bammy of Jamaica come from cassava.

| | | |
|---|---|---|
|  | •  |  |
| **Starch processing** | **Starch flour** | **Starch wet-processing** |
|  | •  |  |
| **Spreading cassava bread to dry** | **Starch being prepared for packaging** | **Starch noodles packaged for shipping** |
|  | •  |  |
| **Picked buds** | **Heavy cake** | **Noodles** |
|  | •  |  |
| **Drying on road to be used for pig and chicken feed** | **Tuber peeled and soaking to reduce toxicity** | **Goats feeding on cassava** |

**Cassava flour on sale**

**Fig. 3. Cassavaproducts**

Additional cassava products include an alcoholic beverage known as kasiri that is made by Indians in South America, the powdery casabe cakes of Yucatán, and tapioca, the only cassava product on northern markets. Cooked cassava leaves can also be eaten and are an important ingredient in soups and stews in parts of Central Africa (Petruzzello, 2024). Cassava root is eaten as a vegetable and is considered to be toxic in raw form which is why it must be cooked before being consumed. The root has a variety of applications, some of which include the production of flour, starch, or ethanol. Cassava leaves can supply a good source of vitamins and protein which can also be consumed after cooking. Cassava hay is used as animal feed and it plays a role in the production of adhesives, textiles, and cosmetics (Anonymous, 2024).

**Toxicity:** Two cyanide-producing sugar derivatives, known as cyanogenic glucosides, occur in varying amounts in most varieties. Indigenous peoples developed a complex refining system to remove the poison by grating, pressing, and heating the tubers. To safely prepare most small "sweet" varieties for use as a vegetable, the skin should be generously peeled off, the tubers must be well cooked, and the cooking water drained off. Some cassava tubers are also soaked beforehand to leach the harmful chemicals. The preparation of cassava flour is usually from larger "bitter" roots, which require significant work to remove the poisons, and can include long soaking times, fermentation, and exposing the cassava paste to the air for several hours. The poison (hydrocyanic acid) has been used for darts and arrows. Improper preparation can cause acute cyanide intoxication, and long-term exposure to the cyanogenic glucosides is associated with goitres, chronic pancreatitis, and a nerve disorder known as ataxic neuropathy (Petruzzello, 2024). The root of the bitter variety is very poisonous when raw. Cooking destroys the hydrocyanic acid making it safe to eat; the cooking water must be discarded **(**Moore and Lawrence, 2024**).**

**Production:** In 2022, world production of cassava root was 330 million tonnes, led by Nigeria with 18% of the total (table). Other major growers were Democratic Republic of the Congo and Thailand. Cassava is the third-largest source of carbohydrates in food in the tropics, after rice and maize , making it an important staple; more than 500 million people depend on it. It offers the advantage of being exceptionally drought-tolerant, and able to grow productively on poor soil. Cassava grows well within 30° of the equator, where it can be produced at up to 2,000 m above sea level, and with 50 to 5,000 mm of rain per year. These environmental tolerances suit it to conditions across much of South America and Africa. Cassava yields a large amount of food energy per unit area of land per day – 1,000,000 kJ/ha (Wikipedia. 2024). The majority of production is in Africa, where 99.1 million metric tons were grown, while 51.5 million metric tons were grown in Asia, and 33.2 million metric tons in Latin America and the Caribbean. However, based on the statistics from the FAO of the United Nations, Thailand is the largest exporting country of Dried Cassava with a total of 77 percent of world export in 2005. The second largest exporting country is Vietnam, with 13.6 percent, followed by Indonesia (5.8 percent) and Costa Rica (2.1 percent) (NWC, 2024). Aside from the cassava variety determining the yield of cassava produce, farming practices and optimal weather conditions are considered necessary in ascertaining cassava yield per hectare. Under optimal conditions, the cassava yields can reach 80 tonnes per hectare. However, nowadays the current world average yield is around 12.8 tonnes with a goal to reach 23.3 tonnes per hectare soon. In Nigeria, 40 tonnes per hectare is attainable with TME 419 cassava variety, but the best recorded was between 10-15 tonnes per hectare. However, very low compared with countries like Thailand. Thailand records an average of 40 tonnes per hectare, employing good agricultural practices compared to Nigerian farmers (Wikifarmer, 2024c). The main cassava production areas in the world are Africa, Asia, the Caribbean and South America. Cassava roots are either directly consumed by humans as food, used as animal feed or for industrial use. Cassava roots can be eaten raw, cooked after removing the skin and rind or even baked and the charred skin removed before consumption. Cassava roots have numerous culinary uses around the world. Cassava leaves can also be consumed as a vegetable. All parts of the cassava plant can be used for animal feeding. In particular, the high energy content of cassava roots makes it an ideal carbohydrate ingredient in animal diet. The majority of the cassava produced in south Asia are used for animal feed in the form of chips and pallets. Cassava roots are also used for industrial purposes, primarily for extraction of starch which has a wide variety of uses. Recently bioethanol production from cassava has received great attention due to increased fossil fuel price and concerns over global climate changes caused by burning fossil fuels (Fei *et al*, 2023).

**Folklore:** In Java, a myth relates that food derives from the body of Dewi Teknowati, who killed herself rather than accept the advances of the god Batara Guru. She was buried, and her lower leg grew into a cassava plant. In Trinidad, folk stories tell of a *saapina* or snake-woman; the word is related to *sabada*, meaning to pound, for what is traditionally a woman's work of pounding cassava. The identity of the Macushi people of Guyana is closely bound up with the growth and processing of cassava in their slash-and-burn subsistence lifestyle. A story tells that the great spirit Makunaima climbed a tree, cutting off pieces with his axe; when they landed on the ground, each piece became a type of animal. The opossum brought the people to the tree, where they found all the types of food, including bitter cassava. A bird told the people how to prepare the cassava safely (Wikipedia. 2024).

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