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HEALTH ISSUES RELATED TO THE PRODUCTION AND CONSUMPTION OF CASSAVA AS A STAPLE FOOD.

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MASTER THESIS 2021

BY

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DECLARATION

I hereby declare that this document is my original thesis for the Master of Science in Plant Science (Biotechnology), and that it contains no content that has been originally written by another party or that has been authorized for an award of any other Master's degree, except where proper acknowledgment has been made in the article.

DEDICATION

I dedicate this thesis to my Godfather, Rev. Tony Goldwyn Amoakohene who has been a rock of stability throughout my University education, and also to my late mother and father, Agnes Dufie and Mr. Joseph Anokye and my entire family.

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ABSTRACT

Cassava plays a vital role in the world's tropical regions. However, it carries varying amounts of cyanogenic glucosides that are a possible human poison. Some forms of malpractices also endanger human health during production.

This research assessed the human health issues related to cassava production and consumption. It described a comprehensive study on cassava roots as a staple carbohydrate and the leaves as vegetables containing vitamin and mineral sources but deficient in amino acids and proteins. It explained that cassava is an essential crop to food security and serves many great purposes economic stability. This work reveals that, cassava contains cyanogenic glycosides (Hydrogen cyanide; HCN) and other anti-nutritional properties that threaten food safety and human health. Cyanogens, when ingested, could cause serious health problems for humans. Detecting and measuring cyanogen amounts in cassava can contribute to the prevention of cyanide poisoning due to the intake of improperly processed cyanogenic cassava.

A concise clarification has been given on the various diseases caused by cyanide intake or cyanide overdose, including konzo, ataxic neuropathy, goiter, and cyanide poisoning. It further described the different processing methods used to remove cyanide from cassava. These also include; boiling, fermentation, steaming, baking, frying, and drying methods. Plant breeders have been able to breed cultivars of cassava with low levels of hydrogen cyanide HCN) using the selection method. Efforts to develop more hydrogen HCN-low cassava varieties should be intensified by research institutes, especially in areas where cassava and its products have been recently introduced.

Moreover, improper farming practices, including improper use of agrochemicals, could lead to low farming populations' vulnerability, thus raising the alarm. The use of agrochemicals in cassava farming should be treated with caution to avoid posing dangers to cassava producers and consumers' health. Cassava-producing farmers should be informed on the need to keep their ecosystem and water supplies free from pathogens and organism-causing diseases.

Keywords: Cassava, Human health, Cyanogen glycosides, Breeding, Agrochemicals.

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CHAPTER 1

1.0 INTRODUCTION

Promoting basic needs, well-being, health, or making the planet free from hunger and poverty is the biggest problem in less developed countries. Zero hunger is the number one goal of the 17 Sustainable Development Goals for 2030 adapted by UN Member states in 2015 (Tsalis *et al.*, 2020). Enough food is one of the primary needs, and all countries need to have this as their main target. The last decade has focused on ways to eradicate global food insecurity and hunger. Cassava serves as the most promising staple crop in terms of new market prospects amongst other agricultural products. It is one of the most highly marketed staple food crops (Omotayo and Oladejo, 2016). Sustainable cassava crops' development includes knowledge of the nutritional properties and health benefits of cassava associated with farming practices, environmental pressures, and plant varieties (Mombo *et al.*, 2017).

Cassava is known to be one of Africa's most highly consumed foods. Due to its importance and versatile nature, it serves as the cornerstone of food security in Africa. Amid its advancement globally, scientific studies on cassava are limited despite its vital position as food in large parts of Africa. In Africa, cassava can be a successful hunger fighter. Obeng *et al.,* 2018 in their work referred to cassava as "bread of the tropics." Cassava's cash income is more moderate than the other broad staples due to cassava's low cash input cost. Cassava, according to reports by Egesi et al. (2006), has grown from a famine reserve product and a staple crop to a cash crop in Africa after the turn of the century. Though it was not a well-known crop outside the tropics, over 200 million people in Africa now contribute to more than 30% of the tropical staple food crops (Dufuor, 1994). Cassava reduces food shortages in Africa because of its high food energy, year-round availability, and tolerance for growth in extreme stress conditions (Alves, 2002).

Cassava is considered a major food crop for millions of marginal farmers and their domesticated animals in tropical regions. However, in Central Africa, cassava's consumption and production are severely declining and have not been replaced by any other major food crop. This has consequently resulted in troubling signs of hunger and malnutrition. However, this region rarely mentions its dependence on the media (Aerni, 2006).

Cassava (*Manihot esculenta* Crantz) is a major crop in Africa that serves as a reserve crop for drought, industrial raw materials and, livestock feed. It belongs to the huge spurge family called *Euphorbiaceae,* which includes much important food, oil and, ornamental crops, such as *Ricinus communis* (castor bean or castor oil plant) *Jatropha curcas* (physic nut) and, *Euphorbia pulcherrima* (poinsettia). There is a wide range of phytotoxins in plants in this family, including diterpene esters, alkaloids, and cyanogenic glycosides. The seeds include the highly toxic carbohydrate-binding protein ricin in the castor bean Ricinus communis (Wedin *et al.*, 1986). In low fertility soils and marginal regions, the crop stores well in the soil with good starch productivity and performs reasonably well. Cassava's diverse uses primarily justify its prominence in the tropics (Cocks, 1985). The majority of cassava grown in Africa is being used for food consumption, with 50% in processed form and 38% in fresh and boil form; 12% is used for animal feed. Cassava is used in many industrialized processes to prepare different food types (Dufour, 1994; Hahn *et al*., 1987).

1.1 PROBLEM STATEMENT

In Africa, cassava cultivation is mainly used as food for consumption (Ogbe *et al.*, 2007). However, the crop can have deadly implications if poorly prepared before consumption. The cassava plant produces cyanide (cyanogenic glucosides), a poisonous compound that can induce vomiting, stomach pain, dizziness, headache, and fatigue when consumed.

Except for the seeds, all other cassava organs contain cyanogenic glucosides (Nugent and Drescher, 2006). Cassava roots contain linamarine glycoside, which when converted into hydrogen cyanide by the linamarinase enzyme causes harmful effects. Several pathological conditions are also associated with chronic cyanide toxicity, including konzo, an irresistible leg paralysis reported in eastern, central, and southern Africa. Such chemicals are harmful to humans and can cause severe health issues (Egwim-Evans *et al.*, 2013).

Gastrointestinal, reproductive, cardiovascular, endocrine, and neurological disorders, cancer, and toxins are associated with agrochemicals used during production. Pesticide overuse is associated with reducing biodiversity, such as bee pollination (Akinpelu *et al.,* 2011). Mycotoxins can also contaminate various food items, including raw materials such as cassava or cereal products

(Roscoe *et al.*, 2008). Aflatoxin contamination has been routinely found in staple crops such as cassava, maize, etc., intended for human or animal consumption (Wild and Hall, 2000).

Cassava also produces other anti-nutrients such as phytate, oxalate, nitrate, fiber, saponins and, polyphenols, in addition to cyanide, which may decrease the bio-availability of nutrients and affect human health in diverse ways (Bandna, 2019).

The emergence of pathogens poses a significant public health risk because they contribute to morbidity and mortality rates. Hydrogen cyanide (HCN) is toxic to humans, and much of the processing of cassava tubers is therefore needed to promote the release and removal of HCN before ingestion (Omojokun, 2013).

1.2 JUSTIFICATION

Cassava's agricultural production and consumption process lead to both good and bad health for both farmers and society. It is not easy to underestimate the value of health as a form of human capital. A determinant of health with income and labour proves the worth of an agricultural producer (Corinna and Ruel, 2006).

Research has shown that cyanide affects people who eat cassava frequently over a long time (Flynn & Haslem, 1995). Cyanide is easily absorbed into the body. Once in the body, it prevents the body's cells from using oxygen by binding to main iron-containing enzymes and halting cellular respiration. The health effects of high cyanide exposure levels will begin in seconds to minutes, and low levels can cause heart failure (Sousa *et al.*, 2002). While cyanide's impact on individuals is currently not seen, particularly at lower doses, considering cyanide's lethality, the probability of its avoidance cannot be risked for any other purpose.

Moreover, agricultural practices are essential to human health, careless and improper farming practices can degrade and contaminate natural resources and harm human health. Health accounts for a more significant share of farmers' inefficiency and calls for attention (Nugent and Drescher, 2006). Much research needs to be conducted to control cyanide levels in cassava and the adoption of improved farm practices.

1.3 RESEARCH QUESTIONS

- ¶ What are the health issues associated with the production and consumption of cassava?
- ¶ What are the factors influencing the health issues of cassava production?
- ¶ What are the farmers' general perceptions of health issues related to cassava production?

1.4 RESEARCH OBJECTIVES

1.4.1 Main objective

To determine the health issues related to the production and consumption of cassava as a staple food.

1.4.2 Specific Objectives

Specifically, this study aims;

- ¶ To determine the health issues associated with the production and consumption of cassava.
- ¶ To determine the factors influencing health issues of cassava production.

CHAPTER 2

2.1 ORIGIN AND BOTANY

Cassava is a perennial shrub that belongs to the family *Euphorbiaceae.* In this family is *Manihot esculenta* Crantz (syn. *Manihot utilissima* Pohl), a single species. Cassava (*Manihot esculenta* Crantz) originated from South (Latin) America, specifically Brazil, 4000 years ago. Populations of wild *M. Esculenta* and *flabellifolia* subspecies, shown to be the progenitors of domesticated cassava, are concentrated in Central-Western Brazil. Allem (2002) stated that in Goias in Central Brazil, the cassava's geographical origin (biological diversity of the Manihot genus) was found close to the cultivated species. He assumed, therefore, that the cassava originated from Brazil. In the USA, cassava was a staple food of pre-Columbian peoples and was often depicted in indigenous art (Alves, 2002).

European traders brought the crop to Africa as a potentially useful food crop after the Americans' discovery (Madukosiri *et al.,* 2017). Okogbenin et al. (2006) also stated that cassava was an indigenous crop to tropical America and was brought during the 16th century by the Portuguese to Africa through the coasts. Cassava was then propagated further by Africans and is now present in almost all areas of tropical Africa. Today, Nigeria and Congo Kinshasa are the primary cassava producers (Cock *et al.*, 2019).

Cassava is cultivated primarily in Africa, the Caribbean, and Asia (Ha *et al.*, 2016). This crop has high carbohydrate levels and is easy to grow. It is a multifunctional plant in various industries, such as fruit, feed, and raw materials (Howeler, 2014). Maize and cassava are now prioritized as staple foods in Tanzania, replacing native African crops (Nweke and Felix, 2005).

Cassava has also become a significant staple in Asia, grown extensively in Indonesia, Thailand, and Vietnam. Cassava was used instead of/or rice, potato, or maize by the Amazonian Indians. The King of Travancore, Vishakham Thirunal Maharaja, struck the kingdom in the South Indian state of Kerala using cassava as a replacement for rice after a great famine. The Indians referred to its use as "Tapioca"(Saraswathy, 2019).

2.2 MORPHOLOGY AND GROWTH OF CASSAVA

Cassava is a woody plant belonging to the Manihot genus and *Euphorbiaceae* family with a height of about 1-3 m (Bombily, 1995). It can hit 1-4 m in height and is primarily cultivated because of its starch roots. Hundreds of varieties of cassava are distributed around the world.

Cassava cultivars are classified according to morphology, e.g., leaf shape and size, plant height, stem colour, petiole length and colour, inflorescence and flower colour, tuber shape and colour, earliness, and root material of cyanogenic glycoside (Nassar and Ortiz, 2007). Cassava yields differ with cultivars, planting season, soil type, and fertility (IFAD & FAO, 2000), as well as the extent of pest and disease infestation and infection, respectively (Bock, 2004).

Propagation of cassava is by stem cutting or seed, but the most common is that of the stem. In breeding programs, seed propagation is generally performed, and this takes a longer time to develop. Seed propagation will result in the recombination of characters and, as such, in genetically diverse plants used to create new varieties (Alves, 2002). The plant has symbodial branching from the main stem; 1 to 4 generating secondary branches that generate other successive branches. As a typical dicotyledonous species, plants propagated from seed produce a traditional primary root system. The germinating seed radical grows downward vertically and develops into a taproot from which adventitious roots derive. The taproot and some of the adventitious roots gradually grow into storage roots. There are adventitious roots in plants grown from stem cuttings that emerge from the basal root surfaces and sometimes from the buds under the soil as shown in figure 1.

Figure 1; The cassava plant.
***Source*;** https://oregonstate.edu/instruct/css/330/eight/images/cassava.jpg

2.3 CLIMATIC AND NUTRIENT REQUIREMENTS OF CASSAVA

Cassava is grown between latitude 30^0 North and 30^0 South over a broad spectrum of edaphic and climatic conditions. The different uses of cassava mostly clarify its prominence in the tropics (Hershey, 2010). The crop stays well in the soil, has a high starchy yield, and functions relatively well in low fertility soils and marginal areas. The ability to grow on poor soils and under challenging climatic conditions and the value of versatile root harvesting whenever there is a need make it the 'last resort crop' for tropical farming families and their domestic animals (Aerni, 2006 ; Hillocks *et al*,. 2001).

Cassava can be grown on marginal soils or increase low soil fertility, making it suitable for growing other crops in regions from sea level up to 2300m. This is because its roots ecologically establish a beneficial symbiotic relationship with mychorriza, enhancing plant nutrients that improve soil moisture and suppresses soil-borne pests such as nematodes (Liu *et al*., 2002; de la Peña *et al.*, 2005). The crop grows on a wide variety of soils, but it adapts well to well-drained, light-textured, deep soils of intermediate fertility. Excellent growth is usually induced at the cost of root growth under high fertility conditions (Cocky, 1984). However, in many soil types, cassava grows well, ranging from light to hard, but deep, well-drained, friable sandy loam to loamy soils. This seems ideal for better root growth (Onwueme and Sinha, 1991). When the drainage ability of the soil is poor, gravelly, saline, or hard-panned, the crop does not grow well because it does not tolerate saline conditions

The optimum pH for cassava growth is about 4.5 and 6.5, but it does well in less than 18% soil's clay content with a pH range of 6-7, thus a well-drained soil. But the crop needs a warm, humid climate with a well-distributed rainfall of 1000mm to 2000mm per year for the best results (Akinpelu et al., 2011). Cassava is now grown under irrigation during both the rainy season and the dry season.

Cassava is subject to highly variable temperatures, photoperiods, solar radiation, and rainfall due to its sizeable ecological diversity. Areas with mean temperature ranges of 25-29°C and a soil temperature of around 30°C support cassava growth but stops growing at a temperature less than 10°C. Although the crop grows well in areas with an annual well-distributed rainfall of 1000-1500 mm, it may withstand semi-arid rainfall conditions as low as 500 mm. Under such conditions, it could have a comparative benefit over other crops (Onwueme and Sinha, 1991).

Nweke et al. (2001) suggested that, with a range of 1-15 different crops, farmers grow an average of 6-7 cassava crops. The crops mostly grown together are corn, yam, and cassava. Hence, mixed cropping is the standard practice for systems that involve cassava.

2.4 IMPORTANCE OF CASSAVA

Cassava is an essential crop in Africa, acting as a reserve for hunger, industrial raw materials, and animal feed (Nweke *et al.*, 2002). It is grown both as food (for humans and animals) and raw material for industrial use (FAO, 2012). It is a significant source of carbohydrates and is the world's third-largest carbohydrate source, with the largest production center being Africa (Alves, 2002). In Africa, cassava can be an effective fighter of hunger. It produces billions of income for both families and government and contributes a lot to food security at many levels (FAO, 2012). Cassava is used for producing a variety of foods in many modern processes.

There is a large proportion of carbohydrates (mainly starch) and minerals in its refined products (Guira, 2013). A large range of products can be processed from cassava, according to Kenyon et al. (2006), a report by the Collaborative Study of cassava in Africa.

Cassava can be boiled or roasted for consumption. However, the fresh peeled tubers can also be eaten as vegetables. The tubers are sometimes added to soups and stews, boiled and pounded into a paste. Since fresh tubers deteriorate rapidly after harvesting (physiological deterioration after harvest; PPD), they are mostly preserved as sundried chips (Kokonte in West Africa) and eaten after cooking or ground into flour. Attiéké, tapioca, gari, flour, starch, fufu, fermented flour, ampesi, alebo, eberebe, ragout, kwadu, kenkey, fede, agbelilakia, placali, yakayake, cossette, lafun, chikwangue, etc. are the main cassava foods found in Africa (Andrew, 2002; Echebiri & Edaba, 2008).

Cassava is used in many food preparations intended for human consumption and in industries such as starch, textiles, petrol, confectionery, etc., and animal feed. It is normally processed into chips for animal feed and into starch for many food and non-food applications. The primary mode of cassava is traditional foods processed at home or in small-scale cottage operations. Ethanol, sugar, biofuel, bread, jelly, thickening agents, custard powder, baby food, glucose, and confectionery are the most important industrial uses of cassava (Echebiri & Edaba, 2008).

In the preparation of bread, biscuits, confectionery, pasta and couscous-like products and the manufacture of adhesives, cassava flour is used. In the foodstuff, textile and paper industries, and the manufacture of plywood and veneer adhesives and glucose and dextrin syrups, cassava starch is used (Kenyon *et al*., 2006). In the textile industry, starch is used to coat yarn in the sizing process, adjust the appearance, alter stiffness, add weight to the fabric, and prepare the dyestuff paste in the printing operation. Starch hydrolysates are also important ingredients in processing industrial inorganic substances like alcohol, gluconic acid, and acetic acid (Balagoplan *et al*., 1998).

Dextrin is generated as a catalyst by heating starch in a dry form with acid/alkaline. It is used in the preparation of adhesives for use in the packaging industry for the lamination of paper tubes, cans and cones in the plywood, paperboard, footwear and cable industries; as printing, publishing and library paste; and as label adhesives for envelopes, postage stamps, rubber tapes, safety matches and many other products (Colonna *et al*., 1987). Starch hydrolysates produced by acid or enzyme treatment of starch hydrolysis are used to convey flavour, texture and coherence to beverages such as soft drinks, fruit juice and milk drinks and a range of foods such as soup, cake and cookies ((Balagoplan *et al*., 1998; Baafi, and Safo-Kantanka, 2007).

On the other hand, Cassava leaves provide opportunities to reduce the protein deficiency in products containing cassava. As a by-product of root harvest, cassava leaf yields of up to 4.60 tons of dry matter per hectare can be made, according to Ravindran (1992). In most industries, the current practice is to return this useful feed resource to the soil as green manure. Cassava leaves are strong mineral sources and rich in vitamin A, ascorbic acid, and contain large quantities of riboflavin. Methionine is deficient, perhaps marginal in tryptophan but abundant in lysine (Eggum 1970; Rogers and Milner 1963; Bokanga, 1995). Particularly in layer rations, it can therefore serve as a valuable source of protein and vitamin A.

Cassava is one of the essential foodstuffs in the tropical world. It is becoming increasingly popular with farmers, particularly in tropical African countries, simply because of its agricultural advantages and its ability to feed populations that are rapidly growing. Households under HIV/AIDS stress also move from high-input to low-input farming systems involving Cassava (FAO, 2008). The roots of cassava are energy-rich, containing mainly starch and soluble carbohydrates, but low in protein. More than 60% of all cassava produced in Africa is expected to be eaten by humans, with about one-third being fed to animals and the rest processed into secondary products (FAO, 2008).

An estimated 70 million individuals gain more than 500 Kcal per day from cassava and more than 500 million individuals eat 100 Kcal per day (Kawano 2003). In contrast, the importance of cassava as a food crop in Africa is evident when its annual per capita consumption is compared to that of the rest of the world. For instance, the world's average annual consumption of cassava in 2001 was about 17kg/capita, Africa's annual consumption was still above 80 kg/capita (Aerni, 2006).

The essence of subsistence farming is part of how a crop that contributes significantly to the diets of over 800 million people (worldwide) can be virtually unknown outside its consumption area. It is not seasonal, has a low deduction cost with low labour requirements and easy cultivation, has the power to grow in suboptimal soils and acts as a safety crop for hunger available for harvesting as required (Hall, 1987). Owing to the low cash input cost of cassava, it's cash income is more sustainable than the other global staples. Cassava has transformed from a famine reserve commodity and rural staple to a cash crop in Africa in recent years, according to Egesi *et al* (2006). Cassava products are consumed in all parts of the world. Even in marginal soils, its adaptability to climatic and soil conditions has endeared cassava to most people who continuously cultivate minimal available soil (Akinpelu *et al.*, 2011).

2.5 PRODUCTION OF CASSAVA

Cassava is mostly produced on marginal and sub-marginal lands in the humid and sub-humid tropics by smallholders (subsistence farmers). Small farms account for more than 90% of production. Today, almost the entire crop is produced in a labour-intensive manner with little to no external inputs. As more commercialized production systems emerge, such as in urban peripheries, where smallholder production will grow rapidly, this trend may shift.

Globally, the five largest cassava producing nations are Nigeria, Brazil, Thailand, Indonesia and Democratic Republic of Congo (DRC) (FAO, 2009). Figure 2 shows a 2010 FAOSTAT report which states that, Africa is the largest cassava producer, followed by Asia and the Americans. In 2010, Nigeria produced 38 million metric tons and 19% of the global market share was the world's leading producer (FAOSTAT, 2015). In Sub-saharan Africa, the major cassava producing countries include Nigeria (53 million mt in 2013), DRC (16 million mt), Ghana (15.9 million mt) and Mozambique (10 million mt). Approximately half of the world's cassava current production comes from Africa, cultivated in around 40 countries (Spencer and Leone, 2017).

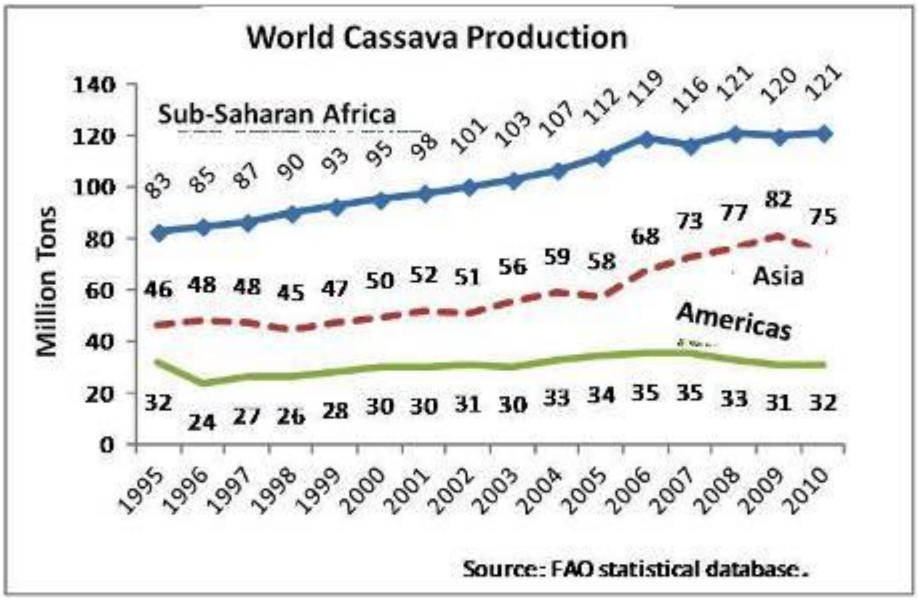


Figure 2: World cassava production as at 2010

Source; https://blogs.worldbank.org/sites/default/files/africacan/cassava_production.jpg

Annual cassava production in all African countries was estimated at 153 million tons in 2012. Production in Nigeria, the leading producer of African cassava, was estimated at 57 million tons in the same year (FAO, 2012).

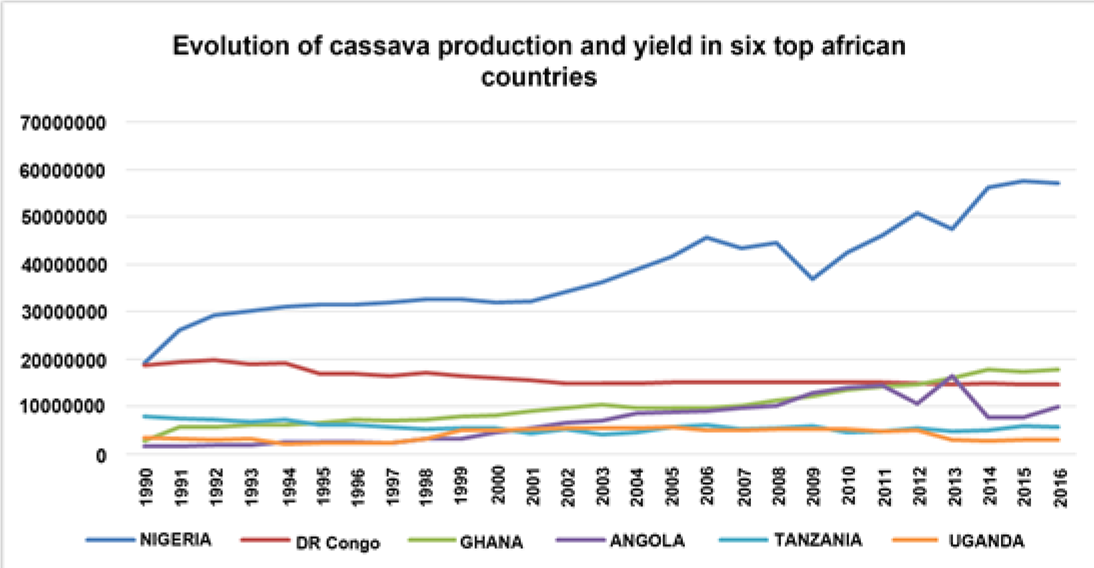


Figure 3; Cassava production trends and average yields in the top six African countries (x10^6 T). ***Source***; https://html.scirp.org/file/3-2604057x2.png (Bisimwa *et al.*, 2019)

Figure 3 explains a calculated cassava yield on production and cultivated surfaces in African countries. Except for Nigeria and Ghana, it is clear that all East and Central African countries experienced a significant reduction in production from 2010-2011, which was most likely due to an uncontrolled spread of the CBSD(Cassava Brown Streak Disease) epidemic that has occurred since that time. This was due to the relative increase in the CBSD pressure. Angola's CBSD outbreak, on the other hand, has yet to be linked to a drop in cassava production. According to FAO data, Nigeria and Ghana have increased cassava production significantly and are now the top African cassava producers.

According to FAO statistics (FAOSTAT, 2015), cassava's world production rose to 263 million tons in 2013 (figure 4), an increase of 27% in production over the last 10 years. Of these, 33.5% contributed to Asia (88.2 million tons), 54.8% to Africa (144.2 million tons), and 11.6% to the Americans. Asia has the highest average yield per hectare of 21.1 tons, far from its actual yield capacity, among these three countries, followed by the Americans (12.3 tons) and Africa (12.3 tons), respectively. As a result, this trend shows that Asia will continue to rise in production and yield. At the same time, Africa, primarily constrained by viral diseases that severely affect crops, is likely to increase planting in the coming years (Chavarriaga- Aguirre *et al.*, 2016).

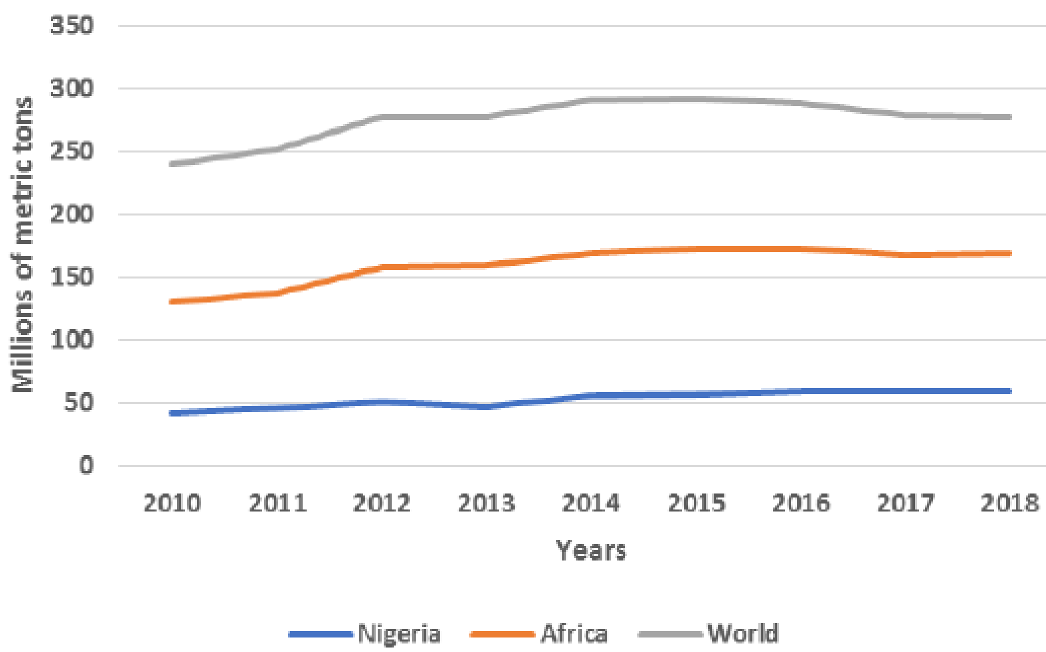


Figure 4; Production of cassava between 2010 and 2018

Source; *FAO (2020)*

Cassava plays five major roles in African processing, hunger-reserve crops, agricultural staple foods, rural and urban cash crops, and feed and chemical raw materials, according to (Nweke *et al.*, 2002). The acceptability of cassava and its products by all Nigerian groups draws close attention to cassava producers (Olanrewaju *et al.*, 2009).

About 65% of the total production of cassava is used for direct human consumption. Of this, approximately half is consumed after cooking the fresh roots and the other half is processed in various ways to make flours or meals. Cassava production in Africa is almost primarily used as food for consumption (Ogbe *et al*., 2007). Approximately 500 million people consume 300 kcal per day as cassava at present, 50 million people consume 500 kcal per day in Africa, and 25 million people consume more than 700kcal per day in southern India (Cock, 1982).

After wheat, rice, and maize, cassava is the fourth most important crop in the developing world, according to FAO (2008). A big shortage in the regional food supply is currently being covered by cereals purchased on the foreign market. Two major hurdles remain for cassava to become an income-earning commodity in the intra-regional sector for smallholder farmers in Africa: post-harvest production and regional trade barriers.

Freshly harvested cassava tubers (figure 6) are more perishable than other big root crops, but the way farmers overcome this is to keep the crop in the ground (figure 5) until necessary (Richard and Coursey, 1981). In fact, in the late 1990s, 95% of the total production of cassava, after accounting for waste, was used as food in Africa, and the total consumption of cassava more than doubled from 24 million tons a year in the early 1960s to 58 million tons a year ((FAOSTAT, 2002).

Globally, the average yield of cassava is only 12-13 t/ha, but its potential yield is almost seven times greater under optimum conditions (80 t/ha; FAO 2013). In West Africa, production doubled roughly from 25.8 million tons in 2004 to 52.3 million tons (FAO, 2006). Ghana is the third largest cassava producer in Africa (FAO, 2006) and currently produces approximately 12,260,000 MT per year.

Figure 5; Cassava plantation in Africa

Source;https://encryptedtbn0.gstatic.com/images?q=tbn%3AANd9GcScGZKPToI00fZuC6AfN5DWwVYI47CS_FpgYQ&usqp=CAU

Figure 6; Harvested cassava roots

Source;https://encryptedtbn0.gstatic.com/images?q=tbn:ANd9GcR4gaa0PKUkawdPXWM4wFDddfHLGCDl7A4-Yw&usqp=CAU

2.6 PESTS AND DISEASES OF CASSAVA

Cassava continues to be the most important food crop in Central Africa. Still, it is strongly affected by genetic erosion, pest infestations and plant diseases because it is a vegetatively propagated crop. It generally responds well to irrigation or higher rainfall conditions and the use of fertilizers. It has many stresses, both as a subsistence crop and an industrial crop, that must be tackled before displaying its true potentials. It may be affected by biotic stresses, which include mainly several pests and diseases. African farmers identify plagues and diseases as significant production constraints (Ndunguru *et al.,* 2005). Cassava's common diseases are cassava mosaic disease, cassava bacterial blight, cassava anthracnose disease, cassava bud necrosis, and root rot.

Some of these diseases affect cassava leaves, trunks and others attack the storage roots (Olugbenga *et al.,* 2011; Miskito *et al.,* 2000). Arthropod pests, including the cassava green mite (*Mononychellus tanajoa* Bonder), cassava mealybug (*Phenaccocus manihoti* Matile-Ferrero), and whitefly (*Bemisia tabaci),* which pose serious damage to the crop, affect the final yield. The *M. tanajoa* and *P. manihoti* mainly cause direct physical damage while *B. tabaci* is primarily important as a virus vector. Cassava mealybug and cassava green mite are both under effective classical biological control (IITA, 2000).

2.6.1 DISEASES OF CASSAVA

The common diseases of cassava are cassava mosaic, cassava bacterial blight, cassava anthracnose, and cassava brown streak (Msikita *et al.*, 2000). The most promising way to manage mosaic disease and bacterial blight is to breed resistant varieties, requiring long and detailed breeding and diffusion process. Meanwhile, the green mite, mosaic disease, and bacterial blight continue to cause yield losses in different parts of Africa (Yaninek, 1994).

2.6.1.1 Cassava Mosaic Disease (cassava mosaic geminiviruses, family: *Geminiviridae*)

Different viruses associated with the geminiviridae family, Begomo virus, are developed due to Cassava Mosaic Disease (CMD). The African cassava mosaic virus that occurs within the leave and stem causes cassava mosaic disease and results in a decline in yield up to 90% (IITA, 2008). While the infection will propagate by exchanging stem cuttings, its accelerated growth is closely associated with the disease's main vector (Hillocks and Thresh 2000; Legg *et al.,* 2002). The disease also has an elevated disease. The typical CMD-contained cassava symptoms (Legg and Thresh 2000) are yellow spots in the leaves, leaf distortion and stunted growth. The leaves are tiny and twisted and plants get stunted when the cassava mosaic attack is serious as shown in figure 7 (Kumar and Legg, 2009). The African Cassava mosaic virus has been linked with high temperatures in the rainy season and growing whitefly populations (Legg *et al.*, 1998).

Figure 7; Cassava Mosaic Disease

data:image/jpeg;base64,/9j/4AAQSkZJRgABAQAAAQABAAD/2wCEAAkGBxITE
hUTExMVFhUXGCAbGBgYGB8ZHRsdHyAeGhoaHxofHighHiAlHyAeITEhJSkrMS
4uGh8zODMtNygtLisBCgoKDg0OGxAQGy8mICYtLS8vLS0vLS8tMC8tLS0tMi0v

2.6.1.2 Cassava Brown Streak Disease (cassava brown streak virus, family: *Potyviridae)*

The disease triggered by the brown streak of cassava is a virus. The only countries reported for the disease are cassava-producing areas in East and South Africa (Kumar *et al.,* 2009). The virus causes leaf yellowing, stem lesions, and roots necrosis, making it toxic and unacceptable for the market (Hillocks and Jennings, 2003). The disease is transmitted mechanically through the propagation of stem cuttings and there is some evidence that different species of whiteflies can transmit the disease, such as *B. afer* (Hillocks and Jennings, 2003), *B. tabaci* (Maruthi *et al.*, 2005) and *Aleurodicus disperses* (Mware *et al.,* 2010). The disease is cassava-exclusive and in East Africa it has caused up to 80% damages (FAO and IFAD 2005). This cassava disease has infected at least 20 million people with an estimated loss of 50 million dollars (IITA, 2007). The symptoms this disease and virus are shown in figure 8a and 8b respectively;

Figure 8(a); Cassava brown streak disease

https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.plantwise.org%2FKnowledgeBank%2Fpmdg%2F2017780042

Figure 8(b); Cassava Brown Streak virus

https://encrypted-tbn0.gstatic.com/images?q=tbn%3AANd9GcRqi2SchfFTuSxIFIZ9pRWdRdKFk

2.6.1.3 Cassava bacterial blight (*Xanthomonas campestrispv. manihotis)*

Bacteria that occur within cassava leaves and stems are responsible for this. Disease identifying signs include the presence in leaves of affected plants with water-drenched spots or lesions. The spots often begin in the veins, sides and tips of the blades (figure 9). When the disease progresses, adjacent spots are joined into large brown patches or bites that kill the blade as it grows (Alvarez *et al.,* 2012). In rainy seasons, the signs are stronger than in dry season. For example, insects like grasshoppers contaminate and spread the disease to healthy cassava plants with bacteria. The disease is more serious in older plants than younger ones (Fanou *et al.,* 2018).

The disease spreads by moving the bacterial causal organism from an infected plant to a new susceptible plant. Sometimes, by cuts or cracks or cuts on the plants and roots, the bacterium reaches the plants. Infected plant stems are the origins of the disease-causing bacterium. Throughout the beginning of new crops, cuttings produced from the tainted stem are often used to transmit the disease. Dead cassava stems and bacterial leaves also serve as sources of the infection. Yield losses of about 20% to 100% may occur if they are not damaged after harvest (FAO, 2012).

Figure 9; Cassava bacterial blight

Source; blog.agrihomegh.com

2.6.1.4 Cassava anthracnose disease

An infection found on the surface of cassava stems and leaves is caused by cassava anthracnose disease (Alvarez *et al.,* 2012). The illness caused by cassava anthracnose occurs on the tips of the leaf petioles as cancers (sores). Cankers soften the petioles enough that the leaf comes back and wilts (Yaninek *et al.,* 2000). The wilted leaves die and are defoliated and the tip of the shoot die-back. Vulnerable sections of cassava become twisted with extreme disease attacks. The disease typically occurs at the rain's onset and rises with the rainy season (Alvarez *et al.,* 2012). Cassava plants with the disorder are the principal cause of cassava anthracnosis (FAO, 2012). The disease spreads from cankers on the stems by the wind or through spreading cancer cuttings. Dead cassava stems and fungal leaves are often considered as a vector of the disease until they are lost after root harvest (Akinbo *et al.,* 2012). The signs of the anthracnose disease is shown in the figure (10) below.

Figure 10; Symptoms of Cassava anthracnose disease

data:image/jpeg;base64,/9j/4AAQSkZJRgABAQAAAQABAAD
/2wCEAAkGBxMSEhUTExIWFhUXGB0bGBcYFxcYFxgYGBcYH
RoYGBcaHSggGholHxoZITEiJSkrLi4uGB8zODMtNygtLisBCgoK

2.6.2 PESTS OF CASSAVA

Throughout sub- Saharan Africa, cassava's green mites, bees, cassava mealy bug, and vertebrate pests (rodents) are among the main pests of cassava. The leaves and stems are fed on by others, while some feed on roots and stems (Olugbenga et al., 2011). The biological control technique is normally used to get the mealybug under control while the green mite's biological control is still in progress (Herren *et al.,* 1987; Yaninek, 1994).

2.6.2.1 Cassava Green Mite (*Mononychellus tanajoa Bondar, family, Tetranichidae*)

The cassava green mite evolved only with its host cassava plant. The mites feed on the plant's terminal parts, destroying leaf cells and decreasing photosynthesis (Gutierrez *et al.,* 1988). The disease occurs on the upper leaf's top surfaces by tiny yellow chlorotic leaf spots of pin size. Severe attacks cause stunting and deforming of the leaves. In Latin America and Sub-Saharan Africa, cassava is the most damaged, particularly in lowlands with a prolonged dry season (FAO, 2013). The mites spread by walking and wind over short distances. They travel over distances by sharing cassava stem cuts and attachments to individuals, vehicles and other physical mediums, across nations and regions (Yaninek *et al.,* 1989). Severe attacks by mites may cause cassava yield losses between 13 and 80 percent (Olugbenga *et al.,* 2011).

2.6.2.2 Whiteflies

The whitefly (*Bemisia tabaci* Gennadius) is a group of cryptic species that are not morphologically distinguishable and have different geographical, biological, and genetic variations (Hsieh *et al.,* 2007). The parasite causes infected food by honeydew secretion, fungal growth and vectoring several plant viruses and direct feeding (Hsieh *et al.,* 2007). Honeydew production is a medium for sooty mold formation, which can reduce output by reducing photosynthesis levels. There are over 600 host plants with *B. tabaci* attacks that contribute to loss of yields of up to 100 % in certain crops (Nunes *et al.*, 2005). Plants may be affected by white flies through the direct feeding of the flower, which causes chlorosis and leaf abscission. The whiteflies inject toxin during feeding to create symptoms such as the silver leaf of pumpkin leaves and irregular tomato maturation (Schuster et al. 1990; Jiménez et al., 1995).

2.6.2.3 Cassava mealy bug

Cassava mealybug, also known as *Phenacoccus manihoti* Matile-Ferrero (Hemiptera: *Pseudococcidae),* is one of the most serious cassava pests in the world (Belloti *et al.*, 1999). As it feeds on cassava, *P. manihoti* causes extreme distortion of terminal roots, yellowing and curling of leaves, decreased internodes, stunting and rotting of stems used for seed reproduction. There is no known complete resistance to *P. manihoti* cassava cultivars. *P. manihoti* is parthenogenic and only produces females. Therefore, an epidemic can only begin with a single adolescent or adult (Parsa *et al.*, 2012). The leaf and root yield, often up to 80%, can be dramatically decreased (IITA, 2008). According to FAO (2013), yield losses in infested plants can be up to 60% of the roots and 100% of the leaves.

2.6.3 PESTS AND DISEASES MANAGEMENT IN CASSAVA PRODUCTION

The easiest way to manage pests and diseases is to cultivate a good cassava crop rather than destroy pests. Combining an optimal planting strategy with the plant, it is advisable to mix plant growth and plant conservation activities to produce a good crop. Several integrated pest management (IPM) methods in cassava are suitable for planting (James *et al.*, 2000). These include site selection, soil management methods, collection of suitable varieties and planting materials. When choosing a variety that will grow against pests, you can find out if the selected variety also has other features that you might like. You will look for cassava plants with sturdy stems and stem branches when picking safe planting material. When choosing a variety that will grow against pests, you can find out if the selected variety also has other features that you might like. It is important to look for cassava plants with sturdy stems and stem branches when picking safe planting material (James *et al.*, 2000).

2.6.3.1 Integrated Pest Management Practices (IPM)

Integrated disease management is a crop protection strategy that combines biological, cultural, physical, and chemical control practices to protect the crop. To monitor the disease properly, one must be aware of the occurrence and extent and the impact on crop yield and quality. A significant benefit of integrated disease management is its use to reduce cultural, health and environmental risks (El Khoury and Makkouk, 2010). According to Alabi et al. (2011), management of cassava pests and diseases in sub-Saharan Africa should combine various strategies for better management. Integrated disease management studies in many crop defenses include using disease-resistant plants, implementing cultural practices, biological control, and chemical control as major components.

2.6.3.2 Biological control

Natural enemies feed on other insects, including large cassava pests, including mites, mealybugs, insect scales and whiteflies. Predators and parasitoids are the common natural enemies used in biological regulation. The small wasps are called "parasitoids." Predators control pests by feeding them on and killing them. Predatory ladybird beetles can help monitor white-scale cassava mealybug or cassava. Predatory beetles are often seen feeding on cassava green mite, but predatory mites are the most effective biological control agents of mite pests, called "phytoseiids."

Another biological control is the use of parasitoids-natural enemies, which destroy insect pests by living and growing inside them (James *et al.*, 2000). According to the FAO (2013), the recommended management practices for cassava include protecting natural enemies, closely monitoring cassava plantations to identify the focal points of infestation, extracting and burying infected plant parts and avoiding the transfer of planting material from place to place.

2.6.3.3 Cultural Practices

Cultural management of cassava disease involves using safe planting material, roughening infected plants, and adjusting the time and cropping method. The value of sanitation such as plant management after harvest, removal of crop debris, cleaning of farm equipment, and roughing in. the sources of pathogens causing cassava diseases in farms reported (IITA, 2000). These are common practices that farmers do in crop production while incorporating these practices takes energy, expertise, and resource availability.

2.6.3.4 Microbial control

Microbial control is a special type of biological control where the natural enemies are microbes (fungi, bacteria, or viruses) that destroy the pests by causing disease in them. Such microbial control agents can occur naturally on cassava farms, and they do their job without damaging the crop or hurting people like other natural enemies (James *et al.,* 2000). Scientists are preparing biopesticides, "which consist of fungus spores mixed in oil as commercial products against the grasshopper.

The drug can be sprayed on weeds like the Siam plant, *Chromolaena odorata* to kill newly hatched nymphs gathering on the plant in large numbers. The product may also be directly sprayed on cassava to destroy grasshopper nymphs and adults on the plant. Biopesticides can be sprayed using the same equipment as ordinary pesticides. Therefore, biopesticides are much healthier than natural pesticides because they are not harmful to humans and domestic animals (James *et al.,* 2000).

2.7 HARVESTING OF CASSAVA

In the cassava production and supply chain, harvesting plays a vital role. After maturity, it includes extracting the whole plants or economic components. The most challenging operation in the production of cassava is harvesting, according to Agbotoye (2003). Research conducted by Addy et al. (2004) also showed that the highest cost of production was cassava harvesting. Harvesting is the most demanding operation in cassava production. It is a highly perishable crop and starts to deteriorate as early as 1-3 days after harvest, so cassava harvesting should be carried out correctly and properly.

Cassava harvesting options require the proper adaptation and implementation of improved harvesting practices applicable to farmers from different parts of the world**.** To ensure good production of improved cassava produce, proper harvesting methods should be adopted.

Cassava is ready for harvesting as soon as storage roots are large enough to satisfy consumer requirements, starting 6 to 7 months after planting (MAP), especially for most of the new cassava cultivars. In cassava harvesting, different techniques are considered. That involves manual and mechanical processing and manual harvesting (Amponsah *et al.*, 2017).

2.7.1 Manual harvesting

Usually, cassava is harvested by hand, raising the lower part of the stem and extracting the roots from the ground, then separating them by hand from the base of the plant. Before performing this operation, the upper parts of the leaf stem are cut. Harvesting tools such as hoe, cutlass, mattock, earth chisel, and others can also be used for manual harvesting. Typically, these devices are used to dig around the standing stem to facilitate the pulling of the roots from the soil until the withdrawn roots are separated from the base of the plant (Amponsah *et al*., 2017).
Especially during the dry season, harvesting cassava manually is tedious when soil moisture is at lower levels. On comparatively dryer (hard) soils, manual harvesting tools are preferred, whereas the manual rooting technique is better suited to soils with relatively higher moisture content. However, when the upper cassava plant biomass is extracted or copped before harvesting, the highest efficiency of manual harvesting is achieved (Amponsah *et al.*, 2017).

2.7.2 Mechanical harvesting

Mechanically, harvesting cassava requires the use of a harvesting tool integrally hitched to a tractor to dig out the roots of the cassava. After cassava uprooting, manual effort may be needed to collect and detach the cassava root tubers. Due to the non-uniform geometry of the roots in the field, mechanical harvesting of cassava is difficult. Nevertheless, a few cassava harvesters have been built and some, mainly by large-scale farmers, are in use. For resource-poor farmers, mechanical harvesting costs are too high (Bokanga, 2002).

It is possible to distinguish mechanized harvesters into semi-mechanized and fully mechanized ones. Whereas all root digging procedures are mechanically performed in fully mechanized harvesters, raising de-rooted roots to the soil surface for transport, only the root digging process is mechanized in the case of semi-mechanized harvesters. In the case of semi-mechanized harvesters, while all root digging procedures are mechanically performed in fully mechanized harvesters, elevating de-rooted roots to the soil surface for transport, only the root digging method is mechanized (Bokanga, 2002).

2.8 FOOD SECURITY AND POSTHARVEST HANDLING OF CASSAVA ROOTS

2.8.1 Cassava for ensuring food security

Food protection guarantees physical and economic access for all human beings to the basic foods required to lead productive and safe lives. The value chain of cassava can turn a country from a state of poverty to self-enrichment through jobs and income generation, especially in the stages of development, processing and industrial use (Chinaka and Okoye 2019). Globally, food security has become a growing concern. Food insecurity is a major cause of death and morbidity globally, combined with insufficient caloric intake, especially in developing countries (Sayre *et al.,* 2011).

Thus, it is now understood that the main staples thus rice, wheat, maize, and soybeans are not the full solutions to world food security. However, cassava has been recognized as a crop capable of meeting global food security needs around the world. For this reason, it has been biotechnologically manipulated for better growth and for higher crop production. There is also great scope for closing the wide yield gap of cassava output through better agronomy, given the current practice of limited use of inputs (Fischer *et al.,* 2012).

In 2013, for example, Nigeria accounted for 19% of the world's total production of cassava, Thailand accounted for 11%, Indonesia accounted for 9%, Brazil (8%) and the Democratic Republic of Congo, which also accounted for 6% respectively, Nigeria seemed to be the leading country in the production of cassava from all indications (Sanginga, 2015). Since 2004-2017, the production of cassava has been increasing with a slight decrease in production, as a result of global demand for commodities as a food security crop for growing populations in emerging markets and industrial cassava goods.

Despite the above, Africans still account for less than 1% of total cassava product exports, because smallholder farmers (25% women) dominate cassava production (Awotide *et al.*, 2015). In many African countries, cassava processing is therefore seen as a male occupation. For at least 300 million people, the root crop is a livelihood source. Nearly 90% of Africa's cassava is used as a staple food for human consumption (Chinaka and Okoye 2019). To this end, the commercialization of the production of cassava in Sub-Saharan Africa should help close the gap by encouraging farmers to invest in additional inputs.

The latest FAO World Food Insecurity Study (FAO, 2003) also points out that the number of undernourished people in Asia and Latin America has decreased but increased in Africa, where Central Africa again shows the greatest rise in the number of malnourished people. This tragedy has a lot to do with political turmoil and the general neglect by international donors and investors in Central Africa; 1000 times more people die each year in Congo than in Palestine, but about half of what Palestine receives is annual foreign aid tailored for Congo (Aerni, 2006).

2.8.2 Postharvest handling of cassava

The quality, sustainability, and safety of the plant lies not just on the pre-harvest factors but also on postharvest management, especially for a crop like cassava with a rapid deterioration rate (Iyer *et al.* 2010 ; Kader and Rolle, 2004).

Postharvest handling of cassava roots includes storage of the fresh root, processing, packaging and storage of the processed product (Opara, 2013). Besides, packaging and storage are the major factors in postharvest handling that ensure the final product's food security and safety (Daramola *et al*. 2010). Packaging guarantees the root's quality by protecting it from bruises and injuries and prevents excessive moisture loss. Also, the stored root influences the quality of the product formed and its yield (Akingbala *et al.*, 2005).

Because of the marginal environments in which cassava is cultivated, its post-harvest processing is often affected by the wide distances to the processing centers and the lack of transport infrastructure, especially roads. Cassava roots are also bulky, containing around 65% water, contributing significantly to physiological degradation after harvest. By increasing the probability of losses and increasing the overall marketing expense, the roots' short shelf life affects many of the marketing choices (Morante *et al.*, 2010).

Furthermore, access to urban markets and processing facilities is limited to production sites that are relatively close to them (Reilly *et al.,* 2001). To date, research on the PPD study has concentrated mainly on biochemical signaling events several hours after harvesting (Iyer *et al.*, 2010). Changes in the nature and form of volatile compounds released, secondary metabolites accumulated, and changes in the expression of main genes in reactive oxygen species (ROS) turnover were primarily observed after analyzing physiological and biochemical changes happening after cassava root detachment (Reilly *et al.*, 2003). Additionally, Vanderschuren et al. (2014) identified glutathione peroxidase as a candidate for reducing PPD based on combined proteomics results, enzymatic activities, and lipid peroxidation assays. Transgenic cassava overexpressing cytosolic glutathione peroxidase in storage roots in this study showed delayed PPD as well as reduced lipid peroxidation hydrogen and peroxide accumulation.

2.9 THE NUTRITIVE AND ANTI-NUTRITIVE VALUE OF CASSAVA

2.9.1 Nutritive value of cassava

The composition and the nutritional properties of cassava depend on the particular tissue (root or leaf). In turn, these aspects depend on several factors, such as geographical location, variety, plant age, and environmental conditions (Montagnac *et al.*, 2009)

Usually, cassava roots serve as a significant energy source. Considering worldwide basis of human diets, cassava is ranked as the 6th most essential energy source and the 4th energy supplier after maize, rice, and sugar (Heuberger, 2005). Also, the dry weight (DW) content of cassava roots, the carbohydrate content amount to 80% to 90% of which 80% is starch (Gil and Buitrago, 2002). The carbohydrate constituents are mainly sucrose, glucose, fructose and maltose (Tewe and Lutaladio, 2004). The leaves are rich in proteins, vitamins (B1, B2, and C), and minerals (iron, zinc, manganese, magnesium, and calcium) and carotenoids (Webeto *et al.*, 2006).

However, both roots and leaves have a huge deficit of methionine and certain nutrients are not optimally distributed within the rest of the physiology of the plant (Gil and Buitrago, 2002) Compared to the leaves, the cassava roots contain very poor lipid levels, nutrients, proteins and vitamins. (Montagnac *et al.*, 2009). Sulfur-containing amino acid-deficient populations, such as those on the African continent, intensify the toxicity of cassava. This implies that, a complete cassava meal with its leaves inclusive contains proteins, vitamins, calories and minerals. Still, it should be supplemented with rich sources of sulfur-containing amino acids to be well balanced.

Table 1 shows the comparison of the mineral contents of 100g of selected foods and cassava. Cassava roots have the highest Ca content after Sorghum with corn having the least. Its iron content is very low and hence need additional supplements in a well balanced meal. The Na and K contents are moderately high with low contents of Mg and Cu.

Table 1; The mineral content of 100 g of various foods compared to cassava root.

Food	**Ca(mg)**	**Fe(mg)**	**Mg(mg)**	**P(mg)**	**K(mg)**	**Na(mg)**	**Cu(mg)**
Cassava root	16	0.27	21	27	271	14	0.1
Potato	12	0.78	23	57	421	6	0.108
Wheat	15	1.17	22	108	107	2	0.144
Rice	9	0.8	35	108	86	1	0.11
Corn	2	0.52	37	89	270	15	0.054
Sorghum	28	4.4	-	287	350	6	-

Source; (Adugna, 2019)

Table 2 shows the carbohydrate content of cassava leaves having the highest value as compared to other edible leaves.

Table 2; Comparison of the carbohydrate content of cassava leaves with others.

Items	**Carbohydrate (g/100g)**
Cassava leaves	7-18
Green snap beans	7.1
Carrots	9.6
Green soybeans	11.1
Green leaf lettuce	2.8
New Zealand spinach	2.5

Source; (Adugna, 2019)

Table 3: Nutritional composition of cassava roots and leaves per 100g

	Fresh cassava root	**Leaves (Fresh)**	**Leaves (cooked)**
Energy kcals	149	91	-
Moisture %	62	71.7	88.3
Protein g	1.2	7.0	8.2
Fat g	0.2	1.0	-
Carbohydrate g	35.7	18.3	-
Fibre mg	1.1	4.0	-
Ca mg	68	303	142
P mg	42	119	352

Fe mg	1.9	7.6	3.0
Retinol mg *Equivalent µg*	-	2000	n/a
Thiamin µg	40	250	-
Riboflavin µg	50	600	-
Niacin mg	0.6	2.4	-
Ascorbic acid mg	31	311	248

Source: Leung, 1968; Food composition table for use in AfricaFAO/US Dept Health. Educ. And Welfare.

In table 3, the nutritional composition of cassava is shown. While it is relatively rich in vitamin C and calcium, the fresh cassava root is made up of water and carbohydrate. It is low in protein and other minerals and vitamins. In some essential amino acids, particularly sulfur-containing methionine), the amino acid profile is low, and the protein content is sometimes even further reduced by traditional methods (Lancaster *et al.*, 1982).

2.9.2 Anti-nutritive value of cassava

Though cassava is deemed an important food crop, it produces its proportion of anti-nutrients, which, depending on the volume of the part being eaten, have either positive or negative health effects (Webeto *et al.,* 2007). They essentially interfere with certain nutrients' digestibility and uptake. Nevertheless, these compounds can also offer benefits to humans, depending on the amount ingested.

Some common anti-nutrients found in cassava are cyanides, phytates, nitrates, polyphenols, oxalates, and saponins. The presence of any of the aforementioned decreases its nutritional value (Montagnac et al., 2009). Human exposures to large concentrations of such chemical compounds are believed to contribute to stomach cancer risk (Cardoso *et al.,* 2002). The most toxic factor which restricts the consumption of cassava roots and leaves is cyanide. The cyanide contents in the cassava bitter varieties exceed the recommended intake; thus, 10mg/kg DW (dry weight) by FAO and WHO (1991), making its consumption poisonous to humans. According to (Siritunga and Sayre 2003), cassava leaves contain 53 to 1300mg/kg cyanide and 10 to 500mg/kg in the root parenchyma.

Table 4: The anti-nutrient levels of cassava (*Manihot esculenta)* in mg/100g of wet weight

Manihot esculenta	**Phytates**	**Oxalates**	**Tannins**	**Cyanide**	**Nitrates**
	191.25	15.74	0.65	25.69	3.58

Source; *Temesgen, 2019.*

From Table 4, phytate content is the highest in cassava roots, followed by cyanide and significant levels of oxalates, tannins, and nitrates. They are known to have binding abilities that affect zinc, calcium, and iron, essential to the body. However, their binding ability causes salt formation, which is highly insoluble and makes minerals less available for absorption. On the other hand, Cyanide causes much more harmful effects to the human body than the other antinutrients (Rhou and Erdmann, 1995).

Continuous intake of small cyanide amounts causes adverse health problems like konzo, goiter, glucose intolerance, tropical neuropathy and others (Ernesto *et al.*, 2002). This could be due to the consumption of poorly processed cassava with high cyanide contents (Montagnac *et al.*, 2009). However, based on the quantity absorbed, some of these substances may also serve as anti-carcinogens and antioxidants.

CHAPTER 3

3.0 CASSAVA AND HUMAN HEALTH

The agricultural production process and its output led to both good and poor health for both farmers and consumers. Every nation looks up to good health and productive agriculture to contribute to their economic stability in fighting against poverty. A determinant of health in relation to income and labour is being an agricultural producer, thus as farmer or labourer (Corinna and Ruel, 2006). Agricultural households derive income from agriculture, which affects their ability to buy and access food, water, land, and health-related resources, thus affecting their overall health status. On the other hand, Labor predisposes producers equally to a variety of workplace hazards, including injuries.

Studies (Schultz, 1999; Strauss and Thomas, 1998) have shown that health and the efficiency of skilled and unskilled labour have a positive relationship. Good health can improve farmer/household income and economic growth linked to labour and output or better production organization. In general, stakeholders in a healthy farming environment have more outstanding intellectual capabilities.

It is difficult to underestimate the value of health as a form of human capital. While agricultural practices are important to human health, careless and improper farming practices can degrade and contaminate natural resources and thus harm human health (Nugent and Drescher, 2006). Health increases work performance and an individual's productivity by increasing physical and mental abilities. Poor health results in low productivity, decrease innovation, and the ability to explore diverse farming practices (Akinpelu, 2011).

Cassava roots contain a glucoside called linamarin which is converted into hydrogen cyanide (HCN) by the enzyme linamarinase. HCN is very toxic to human. Apart from the seeds, almost all organs in cassava contain cyanogenic glucosides (CG). The type of cultivar, environmental condition, cultural practices and plant age among others, are the factors that contribute to the total cyanogenic glucosides concentration (McMahon *et al.*, 1995). Much processing of the tubers is done to promote the release and removal of cyanide before consumption. Fermentation is one of the effective means of removing HCN. For example, in West Africa, the main form in which cassava is eaten is the fermented meal known as gari (Kenyon *et al.*, 2006).

3.1 CYANOGENIC GLYCOSIDES IN CASSAVA

Cassava contains potentially toxic cyanogenic glucosides amounts consisting of 95% of the total cyanogen content of linamarin and 5% lotaustralin. In nearly all cassava tissues, linamarin is present and is synthesized from the amino acid valine (Balagopalan *et al.,* 1988). Hence, the main cyanogenic glucoside that is present in cassava is linamarin. Linamarase comes into contact with linamarin by processing. It catalyzes the hydrolysis to form glucose and acetone cyanohydrin (Mkpong *et al.,* 1990). Acetone cyanohydrin further degrades to acetone and cyanide at a pH 4 and a temperature above 30^{0}C (White *et al.*, 1994).

3.2 HYDROLYSIS OF LINAMARIN

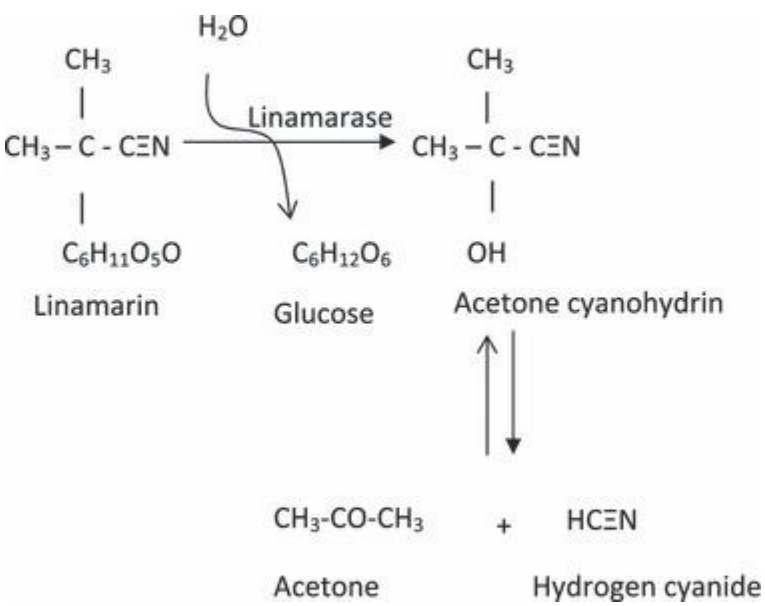
Linamarin (alpha-hydroxybutyronitrile-β-glucopyranoside) and lotaustraulin (ethyl linamarin) are known to be the cyanogenic glycosides of the cassava plant. These cyanogenic glycosides are located in the plant vacuoles. The enzyme, linamarase is located in the cell wall (Gruhnert *et al*., 1994). Hydrolysis of linamarin from cassava starts from the disintegration of the root tissue during processing or chewing to release the endogenous enzyme (linamarase) that hydrolyses linamarin to glucose and acetone cyanohydrins (which are unstable in neutral/alkaline solution).

When the physical barriers between substrates and enzymes break down following cellular structural damage, cyanogenesis is initiated (Poulton, 1990). The capacity of plants and other living organisms to release hydrogen cyanide is cyanogenesis (Ballhorn *et al.,* 2009). The potential toxicity of cassava is connected to the ability to release HCN from accumulated cyanogenic glycosides in all parts of the plant. The vacuole, linamarin, and the cell wall of human neutrophil lipocalin (HNL) in different compartments prevent the development of toxic cyanide in undamaged cells (Nahrstedt, 1993).

Cyanogenic glucosides are not poisonous when intact, but enzymatic action on cyanogenic plants causes release of hydrogen cyanide. This consequently causes potential toxicity issues for animals, including humans. In plants, cyanogenic glycosides serve as important chemical defense against herbivores due to their ability to generate hydrogen cyanide (Zagrobelny *et al.,* 2004; Ganjewala *et al.,* 2010). When converted into cyanide within the body, the residual cyanogens, linamarin and acetone cyanodrin, are the apparent cause of cyanide toxicity in animals and humans. Consumption of 50 to 100mg or 2mol of HCN within 24hours will completely block cellular respiration n adults, leading to death (Rosling, 1994). Consumption of cassava products with high cyanogenic concentrations can result in diseases or even death (Tylleskär *et al.,* 1991).

Acetone cyanohydrin decomposes to acetone and hydrogen cyanide under neutral conditions. Although linamarin and cyanide in foods can be reduced by processing methods, inappropriately processed cassava products can contain some residual linamarin and hydrogen cyanide. This will add to the potential toxicity of products containing cassava. During processing, reduced moisture and/or increased temperature facilitate the spontaneous breakdown of cyanohydrins to toxic hydrogen cyanide (McMahon, 1995).

Figure 11; Conversion of linamarin to hydrogen cyanide



Source;*https://www.researchgate.net/profile/Ramesh_Ray2/publication/215585281/figure/fig2/AS:267525078384653@1440794357290/Microbial-enzymatic-hydrolysis-of-linamarin.png*

Cardoso *et al.,* 2005 and Sirintunga *et al.,* 2004 in their studies reported that linamarin is present in large amounts in the cassava leaves than its roots. Thus there is a higher catalytic potential of the linamarase found in cassava leaves than the roots. Cassava leaves have 10 times the roots' cyanide content and have been used to standardize approaches as a source of linamarin (Haque and Bradbury 2004). There is a second enzyme in the leaves called hydroxynitrile lyase, which catalyzes the synthesis of HCN and acetone through the hydrolysis of acetone cyanohydrin (McMahon *et al.,* 1995). Plant toxins consisting of a-hydroxinitrile glycone and a sugar moiety serve as cyanogenic glycosides (Vetter, 2000).

Cardoso *et al.,* 2005, again reported that different varieties have a range of the total cyanide content from very low to very high (11550ppm) in the parenchyma. In certain species of cassava, only a small amount of cyanide is found in the interior of the roots (parenchyma). This is called sweet cassava, which is common in the South Pacific and can be boiled and eaten (Bradbury and Holloway, 1988). Because linamain is bitter, high cyanide cassava roots containing 100ppm cyanide are usually bitter and are called bitter cassava roots (King and Bradbury, 1995). Bitter cultivars exceed the recommended cyanide intake (10mg/kg DW) by the Food and Agriculture Organization/World Health Organization (1991), making cassava acutely harmful for humans (Montagnac *et al.*, 2008). Acute poisoning fatal to humans has been linked to the intake of 50 to 100mg of cyanide**.** However, cassava crops grown in low altitude areas (below sea level) have been reported to contain high levels of cyanogenic glycosides while those grown in high altitude areas (above sea level) contain low levels of cyanogenic glycosides (Oluwole *et al.,* 2007).

Cassava promotion has become a bit difficult to accept owing to the fact that it contains a cyanogen (linamarin) that releases poisonous cyanide into the body (Madamombe, 2006). It releases hydrocyanide; a volatile poison when linamarin is hydrolysed (Cooke and Coursey, 1981), but the human body can detoxify such cyanides (Oke, 1983). Farmers continue to develop in spite of the toxicity of cyanogenic glucosides. High levels of cyanogenic glucoside crops are cultivated because they act as natural pesticides for the protection of crops from animal pests (Pinto-Zevallos *et al.,* 2016).

Cases of cyanide toxicity have also been reported due to the ingestion of inadequately processed cassava products (Bokanga *et al.,* 1994). The risk of cyanide poisoning from cassava is increased because not only is the component that is eaten extremely cyanogenic, but many countries in Africa, Asia and Latin America very often make up a large proportion of the overall diet (Cliff *et al.,* 1999).

3.3 EFFECTS OF CYANIDE ON HUMAN BODY

Despite the enormous functions of cassava in providing food protection, intake of its products with high cyanide levels can cause acute intoxications, aggravate goitre, induce paralytic diseases, loss of consciousness, lung injury and respiratory failure and sometimes death (Lambri *et al.*, 2013). The occurrence of cyanogenic glycosides in food and fodder can be a significant social and economic problem in many parts of the world. Substantial levels of cyanide may also cause acute poisoning, with symptoms of dizziness, headache, nausea, vomiting, stomach irritation, and diarrhoea (Mlingi *et al.*, 1992). These conditions are excerbated in regions with iodine deficiency (Delange *et al.*, 1994)

Cyanide is a highly toxic substance with both acute and chronic effects due to its ability to impair breathing and the activity of certain metal enzymes (Shibamoto and Bjeldanes, 2009). The residual cyanogens, linamarin and acetone cyanohydrin in cassava, when transformed into cyanide within the body, are obvious sources of cyanide toxicity for humans (Rosling, 1994). Consumption of cassava, which includes residual cyanogens, is associated with numerous health disorders; hyperthyroidism, tropical ataxic neutropathy, and konzo among others (Osuntokun, 1981).

If the plant tissue of cassava is harmed, the vacuole ruptures and cyanogenesis initiates. Linamarin, hydrolysed by the enzyme linamarase, a cell wall-associated glycosidase, is released by the rupture of the vacuole. The damaged tissue by direct ingestion without prior processing, can rapidly decompose and release cyanide by acetone cyanohydrin (McMahon *et al.*, 1995).

Cassava is highly cyanogenic and toxic if not processed (Burns *et al.*, 2012). Improper processing prior to consumption can cause a serious nutritional disease such as konzo or even death, according to Notimérica (2017). Cassava-eating people appear to have a large amount of thiocyanide in the stomach, which may catalyze carcinogenic nitrosamines productions (Cardoso *et al.*, 2002). Most of the ingested cyanide is transformed in thiocyanate when cassava is consumed, a reaction catalyzed by Rhodanese enzyme, which uses part of the S-containing pool of cysteine/cysteine and essential amino acids methionine (Cardoso *et al.*, 2004).

Lundquist et al. (1985) and Rosling et al. (1993) showed that released cyanide primarily binds to methemoglobin in the blood until saturation is achieved. The unbound cyanide forms isothiocyanate by this enzyme rhodanase in the presence of the sulfur-containing amino acids cystine and methionine (Osuntokun, 1981) and subsequently excretes from the body through urine (Westley 1988). Cyanide is, therefore, detoxified in the human body primarily by enzymatic conversion to the much less toxic thiocyanate, Sulphur donors, supplied from sulphur-containing dietary amino acids, cysteine and methionine (Bradbury and Holloway, 1988, Rosling, 1994). A deficiency of these S-containing amino acids would restrict protein synthesis and cause stunting in developing children (Cardoso *et al.,* 2004). In the diet, these amino acids are important because they can be derived only from the food eaten.

Many globally important crops are cyanogenic. These include clover, sorghum and cassava (Jones, 1998). The potential toxicity of food produced from cyanogenic plants depends on the likelihood that consumption could result in concentrations of hydrogen cyanide (HCN) toxic to exposed humans or animals. The ability of herbivores and humans to tolerate HCN depends on the dose and the rate of consumption (Ernesto *et al.,* 2002). It's crucial to know if the concentration is below any acceptable toxicity thresholds. (Burns *et al.,* 2011). The toxicity of cyanide in humans is determined by body size, health status, the amount of cyanide absorbed, and the amount of time it is consumed. Thus, the lethal dose of cyanide is proportional to body weight (Ernesto *et al.*, 2002. According to Deshpande (2002), the lethal dose of cyanide (HCN) of humans ranges from 0.5 to 3.5 mg/kg body weight. Children are known to be more vulnerable than adults to outright poisoning. This susceptibility of children to poisoning by cyanogenic foods has been due to children's lower body mass and, in cassava poisoning, to the children's higher gastric acidity than adults**.** The lethal dose of orally ingested hydrogen cyanide for a 60kg adult man ranges from 30-210 mg equivalent HCN (Nhassico *et al*., 2008).

Jansz and Uluwaduge (1997) documented that damage to the central nervous system in individuals exposed to low cyanide levels over a long period was through their food. In cases of neuropathy (Harris and Koomson, 2011), diabetes mellitus (Morrison *et al.,* 2006), and growth retardation in children (Banea-Mayambu *et al.,* 2000), other studies have included HCN, though intake of up to 100 mg in adults resulted in death in adults (Yeohand Sun, 2001).

The introduction of cassava in new regions must be followed by educating people to eliminate cyanogens in the correct methods of processing cassava, rather than simply ignoring the dangerous aspect of this crop (Madamombe, 2006). To avoid the Konzo, food protection systems have been introduced in many parts of the world.These include the distribution of less toxic varieties of cassava and new processing methods such as wetting the flour for a long time, roasting it directly, scraping the cassava, and moistening the flour. The so-called "gari," a food made from cassava root, is an example of this. It is made by grating, dehydrating, fermenting, and eventually roasting the resulting mash in the form of grains (Barceloux, 2009). Ihedioha and Chineme (2003), in their work, indicated that shortening the cassava mash fermentation time to around 24 hours constitutes a health hazard for gari consumers. To prevent dietary cyanide toxicity, cassava must undergo efficient processing before consumption.

Figure 12 shows a high amount of cyanide content in cassava before scraping, grating, washing and boiling. There is a significant reduction in cyanide content when the outer layer is removed thus up about 78%. Grating further reduced cyanide up to about 77%. Washing and separation reduced the cyanide content about 28% and 18% respectively. Boiling and keeping the grated cassava for days further reduced the cyanogen content to nearly 0% thus, from 8% to 3%.

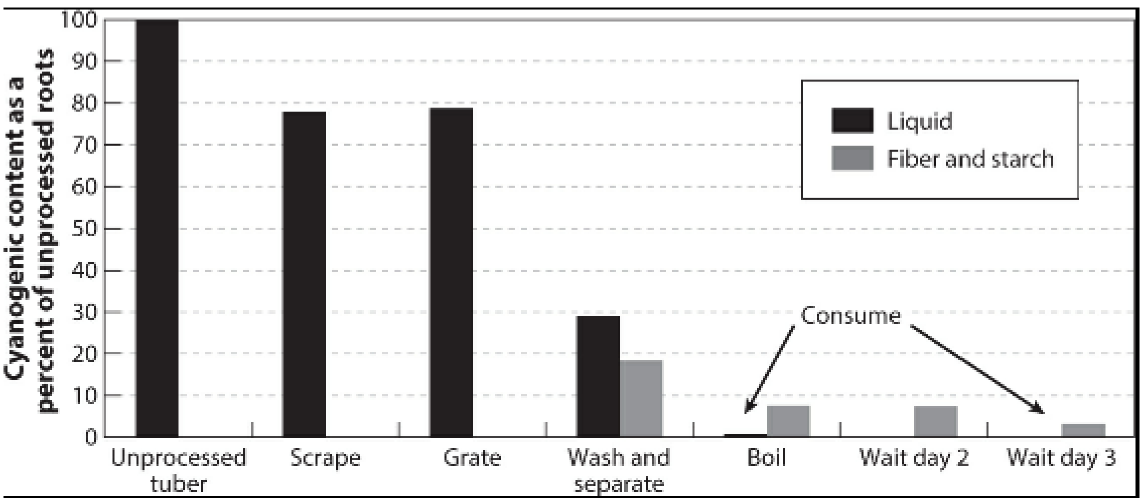


Figure 12; The cyanide content of raw cassava at each step of processing before consumption.

Source;https://4.bp.blogspot.com/PE3rxIBtHZk/W4RP_AHlaLI/AAAAAAAABiU/_8wByYkNBPg2HXyue5Sdw0SYWfFqEdx9QCLcBGAs/w1200-h630-p-k-no-nu/cassava2.PNG

The fast population growth rate in these tropical African countries is linked to the high production rate of cassava, which illustrates the need for adequate health protection against cyanide diseases (Hillocks, 2002). In Africa, dietary use of cassava (*Manihot esculenta Crantz)* has been associated with cyanide poisoning, tropical neuropathy disease and konzo (Tylleskär *et* *al.,* 1992; Mlingi *et al.,* 1992; Teles, 2002; Ernesto *et al.,* 2002). Chronic toxicity is increasingly well documented in cassava-consuming countries (Teles, 2002).

In 1992, cyanide from cyanogenic glycosides of cassava was responsible for the death of three people in Nigeria (Akintowa and Tunwashe, 1992). Recently, five Nigerians apparently died of cyanide poison after eating a meal prepared with cassava flour (Teles, 2002). According to Oluwule and others in 2000, the incidence of tropical ataxic neuropathy was 6% in a Nigerian community, with women (7.9%) being more affected than men (3.9%). The highest incidence was linked to consumption of cassava foods was 24% in women between the ages of 60 and 69 years. However, the number of people with urinary thiocyanate cases due to cassava intake can help determine the konzo-prone communities (Cardoso et al.; 2004). Konzo may be linked to geographical location or seasonal variations. A study in Zaire for instance showed that, incidence of konzo was higher in the savanna regions than forested areas and was associated with increased urinary thiocyanate during the dry season (Banea-Mayambu *et al.,* 1997). From table 5, Nigeria has the highest cyanide-related health problems because its its high production and consumption rate.

Table 5; Cyanide-induced diseases observed in selected African countries**.**

Country	**Food**	**Disorder**
Jamaica	Cassava, Lima beans	Peripheral neuritis
Nigeria	Cassava	Goitre, tropical ataxic neuropathy, cyanide poisoning
Mozambique	Cassava	Severe paralyzing illness (konzo)
Zaire	Cassava	Goitre

Source; (Bolarinwa, 2013).

3.4 DISEASES ASSOCIATED WITH CYANIDE POISONING

Cyanide is a highly fatal and rapidly acting poison. The toxicity of cyanide is largely attributed to cessation of aerobic cell metabolism. The onset signs and symptoms of cyanide poisoning is usually less than 1 minute after inhalation and within a few minutes after ingestion (Hamel, 2011).

The exposure of humans or animals to hydrogen cyanide through the skin, eye or oral ingestion results in absorption and distribution of cyanide in Fe^{2+} in the blood and subsequent binding of hydrogen cyanide with the Fe^{3+}/Fe^{2+} hemoglobin to form cyanohemoglobin. Cyanide also binds to cytochrome oxidase enzyme (present in the mitochondria cell), inactivates the enzyme and causes a reduction in oxygen utilization by the body tissues. This may result in cytotoxic hypoxia, a shift from aerobic metabolism to anaerobic metabolism (because of a decrease in the ATP/ADP ratio) and an increase in the levels of glucose and lactic acid in the blood. Cyanide also inhibits the tricarboxylic acid cycle by decreasing the rate of glycolysis and activating glycogenolysis. This causes a reduction in energy available to the respiratory system, the heart and other cells (Speijers, 1993). Although the toxicity of cyanide can develop over minutes or hours after exposure, exposure to high concentrations of cyanide can cause instant death (Mlingi *et al.*, 1992).

Chronic cyanide exposure of inefficiently processed cassava (in regions of the world where cassava is the major source of dietary energy) have been associated with a number of cyanide-induced disorders, including:

3.4.1 Cyanide poisoning:

Improper cassava processing causes this. The clinical symptoms are vomiting, nausea, dizziness, stomach pains, weakness, headache, diarrhoea and occasionally death (Mlingi *et al*., 1992)

3.4.2 Tropical ataxic neuropathy (TAN):

It occurs in older people due to a monotonous consumption of cyanogenic glycosides from a bitter cassava diet for many years. This consequently results in chronic thiamine deficiency from the inactivation of thiamine cyanogenic glycosides (Adamolekun, 2010a). The disease is characterized by unsteady walking, loss of sensation in the hands and feet, blindness, deafness and weakness (Nhassico *et al.*, 2008) in figure 13.

Figure 13; Painful strains beneath the foot due to ataxic neuropathy.

Source;https://4cy9nx1nwb4f3giw7x37lcaw-wpengine.netdna-ssl.com/wp-content/uploads/sites/10/2020/12/neuropathy-foot-ss-315715109-860x588.jpg

3.4.4 Konzo:

An upper motor neurone disease of acute onset due to continuous large intake of cyanogenic glycosides from insufficiently processed bitter cassava. It also results in thiamine deficiency from the inactivation of thiamine when the sulfur in thiamine is utilized for detoxification of cyanide in the human body. This subsequently causes an irreversible lower limb paralysis in children and women of child-bearing age (Tylleskär *et al.*, 1992; Ernesto *et al.*, 2002) as shown in figures 14a and 14b respectively.

Figure 14a; Konzo disease in children

Source;https://journals.plos.org/plosntds/article/figure/image?size=inline&id=10.1371/journal.pntd.0001051.g004

Figure 14b; Konzo disease in children and adults.

Source; https://pediatrics.aappublications.org/content/pediatrics/131/4/e1231/F1.large.jpg

3.4.5 Goitre (hyperthyroidism):

It results from interference of thiocyanate (the end product of cyanide detoxification in the human body) in iodine metabolism, leading to dietary iodine deficiency and associated disorders (Gbadebo & Oyesanya, 2005). Symptoms of goitre are respectively shown in figure 15.

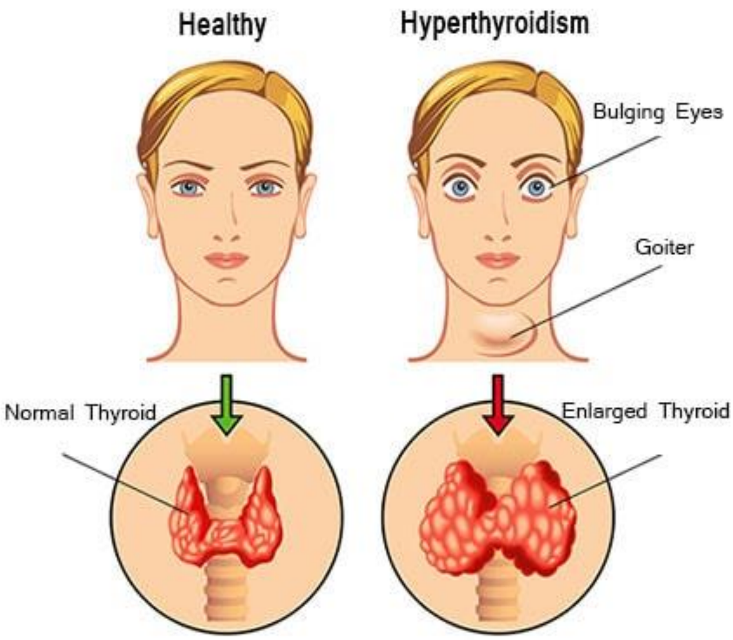


Figure 15; Hyperthyroidism due to cassava poisoning

Source; https://www.planetayurveda.com/pa-wp-images/hyperthyroidism_2.jpg

3.5 REDUCTION OF CYANIDE IN CASSAVA

The presence of toxic cyanogenic glycosides in cassava, together with other factors such as deficiency of certain basic nutrients and high degradation rate, constitutes a vital limiting factor for its use. Cassava tubers and leaves are used as raw materials for human food, animal feed and industrial use. Although rich in starch, the tubers have a low protein content (<2%) and have a short shelf life. The presence of cyanogenic glucosides (linamarin and lotaustralin) is a major factor limiting its food value (Vetter, 2000). Due to their potential health effects, the presence of these toxic compounds in cassava and its food products has been a cause of concern. Therefore, there is the need to eliminate these harmful compounds before consumption to ensure safety (Nambisan, 2011).

Cyanogenesis regulation in cassava can be tackled both through genetic enhancement and through the promotion of efficient processing. In the short term, processing has been recognized as the most successful way of regulating cassava cyanogens (Nambisan, 2011).

In detoxifying cassava (especially during processing) for human consumption, autolysis of linamarin is widely used. This is caused by maceration or cell disruption, which results in bringing linamarase into contact with the glycosides and hydrolysing them. However, the activity of linamarase decreases several days after harvesting (Iwatsuki et al., 1984). The reason responsible for this lowered activity is not clear but has been linked to the formation of enzyme inhibiting compounds such as polyphenols (Essers *et al.*, 1996).

Cyanide reduction by breeding/genetic engineering and processing creates an incentive for the economic and social prospects of the plant to be scaled up by this debacle. This decreases cyanogenic compound exposure and thereby reduces or removes the chance of cyanide intoxication (Onabolu *et al.*, 2002). The issue of dietary cyanogen exposure can be solved for populations that rely on cassava as a staple crop only by using cultivars with a low cyanogen content (linamarin) or, instead, if high cyanogen cultivars are used, they should be adequately processed to reduce the cyanogen content to safe levels (Nambisan, 2011). There are various ways that can be adopted to remove/reduce the cyanide content before consumption to avoid poisoning. These methods are as follows;

3.5.1 Reduction of cyanide by processing methods

In cassava-consuming cultures, a large range of processing methods is used. Most of these processing methods effectively reduce the content of cyano-glucoside (CNG) (Dufour, 1988; Mlingi and Bainbridge, 1994). They either lead to the hydrolysis of CNG, depending on the nature of the process, to the release of acetone cyanohydrin and cyanide, which are volatilized and subsequently lost, or to the release of highly soluble CNG and its hydrolytic products into water (Nambisan, 2011).

The cyanide-induced disease can be prevented by effective removal of cyanogenic compounds in food plants before consumption. Cyanogenic plants are subjected to various processing methods such as cooking (boiling), steaming, roasting, baking and other processes such as peeling, soaking, grating, fermentation and sun drying, to reduce their cyanide content to safe levels (Cardoso *et al.*, 2005; Perera, 2010) as shown in the figure(16) below;

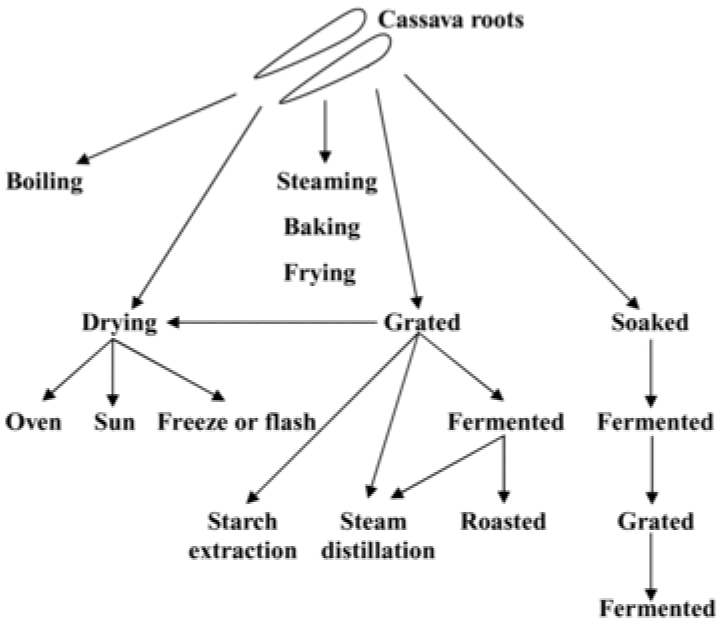


Figure 16; Cyanide reduction methods in cassava roots

Source; Montagnac *et al.,* 2008

3.5.1.1 Boiling

Free cyanide and cyanohydrin are present at very low concentrations in boiled cassava roots. It is not an efficient process for extracting cyanide (50% cyanide removal). This processing method's inefficiency is due to the high temperatures. Linamarase is denatured at 100°C and cannot be hydrolyzed into cyanohydrin. Cooke and Maduagwu (1978) recorded that, after 25 minutes of boiling, bound glucosides were reduced to 45% to 50 %.

Nambisan (1994) found that cyanohydrin and free cyanide made up 6% of the overall cyanogen content was noted in 50g of boiled cassava roots, but only 3% in small pieces. In addition, Oke (1994) documented the volatilization of cyanohydrin and free cyanide during boiling, which reduced the cyanogen content of boiled cassava roots. The heat denatured the enzyme, linamarase and stopped cyanide release and the possible retention of cyanogenic glycosides levels. When the volume of water is increased and the size of cassava to be boiled is decreased, there is efficiency in cyanide removal. This is because the large volume of water dissolves the cyanogens from the smaller surfaces faster than those of bigger units (Oke, 1994).

3.5.1.2 Steaming, baking, and frying

Due to processing temperatures above 100°C and the stability of linamarin in neutral or weak acid conditions, the loss of cyanide resulting from steaming, baking, or frying is minimal (Bradbury *et al.,* 1991). These methods are only acceptable for sweet cassava, which is popular in the South Pacific because it contains low cyanide levels (Bradbury and Holloway, 1988).

3.5.1.3 Drying method

Drying involves two methods: mechanical drying (for example, oven drying) and natural drying by the sun. In the drying process, endogeneous linamarase regulates the cyanogenic glucoside removal, resulting in cyanohydrin and free cyanide accumulation in dried cassava (Nambisan, 2011).

During sun-drying, cyanide retention is lower than in oven drying since the temperatures remain well below 55°C. These temperatures are suitable for the activity of linamarase, resulting in improved cyanogen degradation. Free cyanide content has been reported in oven-dried cyanogens at 30% and in sun-dried cassava at 60% (Gomez *et al.,* 1984). As the activity of linamarase in the sun-drying stage is higher, more linamarin is deglycosylated into cyanohydrin and therefore accumulates cyanohydrin and free cyanide. However, during sun-drying, chip thickness can still be a significant factor in cyanogen removal because thin chips dry faster (Nambisan, 2011).

Drying is not generally an effective means of detoxification, especially in the case of cassava varieties with high initial cyanogen glucoside content. During sun drying, cyanogenic glucoside breakdown depends on enzymatic hydrolysis and gradual disintegration of root cells. Thinner bits of cassava dry faster and linamarase is inactivated at low moisture content levels (13%), and cyanogen glucoside avoids breaking down (Mlingi and Bainbridge, 1994). With full sun-drying, cyanohydrin removal is increased. A potential reason may be that root dehydration and moisture loss leads to changes in pH, affecting the stability of cyanohydrin (Mlingi and Bainbridge, 1994).

3.5.1.4 Fermentation

A processing technique widely used in Africa is fermentation by lactic acid bacteria. It is achieved with cassava roots grated or soaked and results in a decrease in pH value. Due to cyanogen removal processes, the performance of the two kinds of fermentation (traditional and conventional) varies. In the traditional fermentation process, there is efficiency in extracting cyanogen glucosides in the grated cassava roots. Westby and Choo (1994) reported removing 95% of linamarin within 3hours after grating. Vasconcelos et al. (1990) found that microorganisms played only a small role in cyanogen reduction and that grating was primarily responsible for linamarin hydrolysis.

While linamarin is easily removed by grating, in products of grated and fermented cassava roots, cyanide retention remains large. In terms of cyanogen reduction, the fermentation of soaked roots in water is much more successful than grated roots (Coulin *et al.,* 2006). Westby and Cho in 1994 reported that, after 3 days of fermentation, more than 90% of the total cyanogens were extracted and about 1/3 of the initial linamarin was contained in the water. No substantial cyanohydrin or free cyanide accumulation was observed. Hence, making microbial growth a necessity for the extraction of cyanogens in cassava. When the soaking and fermentation times are increased, and the roots are peeled and grated afterwards, the cyanogen removal process can be enhanced (Oke, 1994). Dufour (1994) also showed that a 98% cyanide removal was achieved by soaking cassava roots for 6 days, grating them on the sixth day, and fermenting the mash obtained for 4 days. For example, in table 6, the HCN content of bitter cassava roots decreased with increasing number of soaking days.

Table 6; Effects of soaking on the HCN content of bitter cassava roots.

Soaking period (days)	Remaining HCN (percentage)
0	100.0
1	55.0
2	42.3
3	19.0
4	10.9
5	2.7

Source; Bourdoux *et al.,* 1983

Table 7 shows a summary of the relative cyanide reduction of each step during the preparation of attieke (product of cassava) for two groups of cassava with different cyanide contents. For both the low and high cyanide groups, fermentation greatly decreased the content of cyanide. In the high cyanide group, however, the 58% decrease was even higher than for the low 41% cyanide group**.** Linamarase activity was probably higher in the high cyanide group than in the low cyanide group and more cyanohydrin and HCN were generated. For both classes, the pressing move reduced the cyanide content by about 20%. The cyanide reduction was not pronounced during granulation and drying. Final steaming did, however, play an important role in reducing the content of cyanide to low levels. The cyanide content of the final product for the two classes was 1.6% of the original cyanide content of the roots.

Table 7; Relative cyanide reduction content at each step of attieke preparation

	Low initial cyanide content reduction in %	**High initial cyanide content reduction in %**
Fermentation	40.9	58.1
Pressing	20.7	20.6
Granulation	13.9	6.8
Drying	7.6	2.5
Steaming	15.1	10.5
Attieke (remaining cyanide)	3.9 mg/kg dwt	9.3 mg/kg dwt

Source; (Heuberger, 2005).

3.5.2 Detoxification of cassava cyanogens by breeding

Though cassava is economically significant in many parts of the world, less consideration has been devoted to breeding for improving this crop relative to many other crops. There is virtually no information available on realistic and basic breeding approaches to solving many of the problems that limit or impede cassava use or production.

Cassava breeding aims to integrate all the characteristics not yet thoroughly explored into clonal cultivars that tend to be consistent with high yield expressed both in terms of quantity and quality per area and time unit. Breeding targets increasing both quantity and quality yields by producing breeds resistant to diseases such as bacterial blight and mosaic of cassava, climatic and environmental adaptation, high starch, and zero cyanide varieties (Ceballos *et al.,* 2012).

Research works on cassava breeding programs began in the 1970s. Kawano et al. in 1998 and 2003 officially produced varieties of fresh root yield (FRY) and dry matter content (DMC) with noticeable increment by using the selection method. They observed that selection affected the relationship between FRY and DMC. The selection process favors genotypes with high dry matter productivity through either high Fresh root yield(FRY) or high Dry matter content (DMC). Still, it is challenging to identify genotypes that are excellent for both traits simultaneously (Ceballos and Hershey, 2016).

The marker-assisted molecular mapping method was the only method that aided selection during cassava breeding and produced breeds resistant to cassava mosaic disease (CMD). This impact rather limited the levels of producing fresh root yields (Okogbenin *et al.,* 2013).

Genomic selection is the new selection method adopted by many cassava breeders after numerous researches done by scientists. It is deemed to have increased productivity after several tests (de Oliveira *et al.,* 2012). It is a type of marker-assisted selection involving genomic estimated breeding values to sort out individual species (Nakaya and Isobe, 2012). Genomic selection relies on calculating breeding values dependent on whole-genome genotypes for quantitative traits by simultaneously estimating the marker effects in a single step. (Heslot *et al.,* 2012).

In their works, Ceballos and other Researchers proposed using phenotypic data to resort to the breeding value for cassava enhancement (Ceballos *et al.,* 2004). In 1981, Falconer defined breeding value as the mean value of the progeny of an individual. He further explained that it is the deviation of the progeny out of a given progenitor with respect to reference population thus, this value depends on the average performance of the reference population and the individual allelic value transferred from a particular progeny (Falconer 1981). Usually, breeding value is linked to additive genetic effects. In contrast, breeding values may be affected by such dominance effects (e.g., a single dominant resistance source to a given disease or pest).

Considering the cyanide content of cassava, wild cassava cultivars are known with greater yield, improved resistance to pests, and prolonged soil storage than sweet cultivars, but they are bitter, and hence, they have a poor market value (Ndubuisi & Chidiebere, 2018). They have a cyanogenic content of 2000ppm dry weight, which is about 200 times the acceptable amount (<10 ppm) that meets WHO's recommendation (Ndubuisi & Chidiebere, 2018). This means that wild cultivars exceed the minimum intake for humans. Some farmers, however, disregard this danger and still grow these cultivars due to their high yield potential. Sweet cassava cultivars, however, contain low levels of cyanogens, unlike the bitter cultivars (up to 100 ppm) but cannot be eaten raw without processing. This processing activity triggers enzymatic degradation of cyanogenic glycosides. Shortening the oxidation time causes insufficient enzymatic degradation, thus the preservation of high concentrations of cyanogen glycosides. Most farmers fail to follow recommended procedures during the dry seasons and consequently produce yields with high levels cyanogenic glycosides that affect human health after consumption (Ndubuisi & Chidiebere, 2018).

CHAPTER 4

4.0 EFFECT OF PESTICIDES/AGROCHEMICALS ON HUMAN HEALTH DURING CASSAVA PRODUCTION

The health effects of agricultural chemicals (pre- and post- emergence herbicides, insecticides, pesticides, etc.) used in the production of cassava result from their degree of accumulation in soil, air, water, plants and the level of human exposure.

Human health and the environment can be prone to danger by the use of pesticides. Their long-term work-related low quantity exposure effects are difficult to track as they include transitory and non-specific health impacts. It can also rely on the means of exposure and exposure regularity of the pesticide used, time and application approaches, not forgetting the use of personal protective equipment.

There is an estimation that, only 0.1% of pesticides usually reach pests, while the remainder remain in the atmosphere or on food. Overuse of pesticides, such as pollinating, is also associated with decreasing biodiversity (Nugent and Drescher, 2006). Both processes have health consequences while difficult to quantify. The acute effects on farmworkers who use pesticides are even more measurable: millions suffer from the ill health effects of pesticides every year, especially in developing countries. Intestinal, cardiovascular, gastrointestinal, neurological, reproductive, and endocrine diseases and cancers and toxicity have been related to their exposure directly and indirectly to agricultural chemicals.

Gatto *et al.* (2014) found that findings from human studies indicate that exposure to neurotoxic pesticides would cause harm to the central auditory system in a study to investigate the impact of neurotoxic pesticides on hearing loss. Pesticide sprayers report greater signs and symptoms of exposure than other field employees, such as skin irritation, stomach poisoning, and eye irritation.

Chronic diseases like diabetes, cardiovascular diseases (hypertension), chronic respiratory diseases (e.g., asthma), chronic fatigue syndrome, systemic lupus erythematosus, rheumatoid arthritis, all forms of malignancies, Alzheimer's, reproductive disorders, Parkinson's disease, Congenital nephropathy disorders etc. are main conditions in the 21st century that impact public health after exposure to pesticides.

Many clinical studies display immense fear of intoxication. The presence of chemical residues of organo-chlorine, including DDT, in the breast milk and human blood of vegetable farmers was reported. Some female farmers have acquired residues of pesticides in breast milk beyond the limits for "tolerable daily intake," above which they have adverse health effects on their children (Sudaryanto *et al*., 2005). Depending on the pesticide involved and the means of exposure, the negative health effects that occur due to exposure to pesticides vary, with the dermal route being the maximum, especially for sprinklers or applicators (MacFarlane *et al.*, 2013).

Pesticide exposure occurs mainly through oral (ingestion), dermal, eye and nasal (inhalation); through food or from the atmosphere due to their wide-ranging and well-known use in agronomy and the home environment. Many health consequences, such as malignancies, neurodegenerative diseases and reproductive disorders, have been attributed to contact with pesticides (Appiah Kubi, 2019). Many pesticides, including humans and livestock, are harmful to non-target organisms and may have detrimental health effects short-term or long-term (Remoundou, 2014). As a result of mixing, loading, application or interaction with sprayed crops, occupational exposure may occur acutely. The risk of contamination rises as farmers disregard safety guidelines on the correct use of pesticides, PPE, and the adaptation of sanitary practices (Damalas, 2007).

Dey (2010) found many respondents (25%) who smoked or ingested other products while spraying/applying, which is an inappropriate activity. Farmers who sprayed in the wrong direction concerning the wind often had increased exposure; this resulted from poor maintenance of most of their facilities or pre-use screening for leakages.

CHAPTER 5

5.0 CONCLUSIONS

This research looked into the health issues related to the production and consumption of cassava as a staple crop. It was discovered that, despite the many benefits associated with cassava production for the subsistence Farmer, it is disadvantaged with possible negative effects like konzo, tropical neuropathy, endemic goitre, tropical diabetes and many others when consumed without proper processing. This is due to the carcinogenic potential of cassava; thus, a cyanide that contributes to an acute or chronic toxicity of human health. Efforts should be made to use the right processing approaches like fermentation, boiling, drying, frying and steaming to dramatically reduce nutritional hazards (cyanide contents) while retaining a high potential for improving human well-being. However producing cyanide-free or disease-free varieties could also reduce the risk of intake.

Poor usage of agrochemicals and farming practices could also put the Farmer's health at risk. During cassava production, the use of agrochemicals should be viewed with caution. Farmers should be well informed on the use of agrochemicals and the risks that come with abusing them. They should adhere to the use of protective clothings like overalls, nose and face masks, safety boots and others when applying agrochemicals.

Paying careful attention to the above mentioned strategies could eliminate the dietary hazards of cassava and its dependence. A system strategy must be analysed and followed to understand and arrive at a more practical assessment of cassava-dependent problems. Subsequent efforts should be made to educate Farmers and consumers in the cassava industry on the importance of keeping pathogens and disease-causing organisms out of production areas to avoid contamination.

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