Review Article

WASTE-TO-WEALTH APPLICATIONS OF CASSAVA– A REVIEW STUDY OF INDUSTRIAL AND AGRICULTURAL APPLICATIONS

ABSTRACT

Cassava plant and its products have long been used as food and feed but lately as industrial ingredients. The present study unveils various agricultural and industrial applications of cassava especially the waste cyanogenic component which hitherto has constituted a huge agricultural waste. The study reviewed current engineering values which cassava cyanide has created in the industrial sector. Some very exciting ongoing research studies on engineering applications of the cassava cyanogenic glucoside are also highlighted.

Keywords: *cyanogenic glucoside,* cassava, cyanide, pack-cyaniding, linamarin, waste

1.0 INTRODUCTION

Cassava started in Brazil and Paraguay but was carried to Africa by Portuguese traders from the Americas. It is a perennial woody shrub, grown as an annual crop and serves as a major source of low cost carbohydrates for populations in the humid tropics [1]. In the past, the largest producer of cassava was Brazil; followed by Thailand, Nigeria, Zaire and Indonesia [1] but today Nigeria is the largest producer [2].

The cultivation of cassava is basically simple. Cassava is a tropical root crop, requiring at least 8 months of warm weather to produce a crop. Cassava does not tolerate freezing conditions. It tolerates a wide range of soil pH 4.0 to 8.0 and is most productive in full sun [1]. Cassava has achieved considerable agricultural importance as the major source of tapioca and fodder for cattle, particularly in the European Economic Community [3, 4]. The utilization of cassava in human and animal nutrition is however, limited by the possibility of chronic and acute cyanide toxicity resulting from continuous consumption [5].

Cyanide is a carbon nitrogen radical, which may be found in a wide variety of life forms and their large scale presence in the environment is attributed to the manufactured sources which are used extensively in industries [6]. Cyanide is highly toxic to living organisms, particularly in inactivating the respiration system by tightly binding to terminal oxidase. Cyanide was toxic to humans and mammals because it binds to key iron containing enzyme Cytochrome oxidase required for cells to use oxygen [7].

Pack-cyaniding of mild steel using cassava leaves and the characterization of the case formed has been reported [8, 9, 10]. The presence of cyanogenic glucoside in cassava plant could have come from the accumulation of products of catabolism of amino acids [11] or a mechanism for deterring predators [12].

Cassava has achieved considerable agricultural importance as a staple food for more than 500 million people, especially in the tropics [13]. Previous investigation into this cyanide toxicity [14, 15, 16] was aimed at destroying the cyanide content in order to render cassava less harmful to the consuming populace [17].

Earlier work has investigated the industrial utilization of the cyanide product in cassava especially in the cyanidation of gold [17]. Ibironke *et al*. [8] studied the case-depth measurement, with the utilization of mathematical modeling, for the pack-cyaniding process using cassava leaves. Adetunji *et al*. [9] reported metallographic studies of pack cyanided mild steel using cassava leaves. Akinluwade *et al*. [18] developed an environmentally friendly in-situ pack-cyaniding technique. The study concluded that pack-cyaniding was feasible with cassava leaves and has the potential to boost the economic viability of the plant for a developing economy. Akpa [19] investigates possible improvement in the properties of the adhesives produced from cassava cyanide by studying the effects of borax and temperature on the viscosity, density and pH of adhesive and the use of two different modifiers (HCL and NaOH) in the production of the adhesive; thus provide a range of conditions for producing starch-based adhesives for diverse applications depending on the required properties and industrial applications. Akinluwade *et al*. [20] studied visible diffusion zone of mild steel pack-cyanided in processed cassava leaves using light and electron microscopes. He found that the visible diffusion zone is a region of high carbon concentration owing to diffusion of carbon from processed cassava powder and that the microstructure of the cases consists of a predominant pearlite phase while the cores are composed of predominant ferrite for high temperature pack cyaniding. Ogundare [21] undertook the production of gold nanoparticles from gold ore leached with cyanide sourced from cassava peels and leaves. Gordon *et al*. [22] investigated the influence of severe plastic deformation on tribological properties of mild steel samples case-hardened using processed cassava leaves. AttahDaniel *et al*. [23] investigated the harmful effect of cyanogenic potential of cassava to Man in the environment and listed applications of cyanide to include electroplating and surface treatment; extraction of gold and silver from the ores. It is also used as a reducing, dehalogenating, polymerizing, decolorizing, dehydrating, or condensing agent in many organic reactions. Arthur *et al*. [24] carried out analytical modeling of carbon and nitrogen concentration profiles of cassava-leaf-enhanced carbonitrided steel.

Cyanide compounds are commonly used when plating zinc, copper, cadmium, brass, gold and silver. The most common cyanide compounds used in metal plating baths are sodium and potassium cyanide and the cyanide compounds of the metal being plated, such as copper cyanide or silver cyanide. Advantages of cyanide plating baths include the fact that they accommodate a wide range of electrical current and are good at removing tarnish or films from objects to be plated [25].

2.0 REVIEW STUDY

Cassava roots are conventionally processed by different methods, which reduce their toxicity, improve palatability and convert the perishable fresh root into stable products. The processing of cassava into its useful products is discussed in the following paragraphs.

2.1 Food and Feed

Garri is a creamy white, starchy, pre-cooked grit produced by fermentation of peeled, washed and mashed cassava roots which are dehydrated, sieved and roasted [26]. In Nigeria, over 70% of the cassava yield is processed into *garri* [27]. Its ability to store well and its acceptance as a convenience food are responsible for its popularity in West and Central Africa where it is a staple food.

The consumption of improperly processed cassava with high cyanogen content has been associated with cretinism, endemic goiter [28, 29] and even death. In addition to the toxic effect, the use of cassava roots as food is limited by their low protein content, short shelf life [30] and seasonal variability.

According to Grace [31], the traditional processing technique for *garri* production has been modified to include: (a) addition of water to the freshly grated cassava at 75% (v/w) level, heating at 50°C for 6 h and equilibrating with a 3-day fermented cassava liquor (40% v/w) for 12-18 h, dewatering and toasting, (b) the fresh tubers are peeled, washed, sliced and dried into chips which are then milled and fermented or rehydrated by addition of water and fresh cassava mash fermented, dehydrated and sieved before roasting to produce *garri* [32].

Cassava roots and cassava leaves are both used for animal feed [33, 34]. Cassava roots are rich in digestible carbohydrates, mainly in starch. Cassava starch granules are composed mainly of two polysaccharides, amylase (20%) and amylopectin (80%) [35]. Therefore, cassava roots are low in protein and fat. Cassava root has less than the recommended minimum limit in almost all essential amino acids, except tryptophan [36]. Cassava leaves are much richer in protein than the roots, although the leaf contains a lower proportion of methionine than the root protein. Cassava is good source of dietary fibre, magnesium, sodium, riboflavin, thiamine, nicotinic acid and citrate [37]. Cassava however contains cyanogenic glycosides linamarin and lotaustralin in a ratio of 97:7 in all its tissues except for the seeds [38]. Cassava is usually classified by farmers as being bitter or sweet depending on the levels of anti-nutritional factors therein. Cassava varieties with bitter taste are considered toxic [39].

In order to reduce toxicity and improve palatability of cassava, various treatment methods are applied. Such methods include, peeling, boiling, steaming, shredding, roasting, fermentation, however the most common practices is drying of the roots after chipping [40]. The majority of farmers in Southern Africa prefer to grow the bitter varieties of cassava as a form of crop protection measure against pests. It is therefore imperative that cassava must me adequately processed or treated before it is used as an animal feed [41].

2.2 Processing Cassava for Animal Feeds

This section discusses the processing of cassava into animal feed in the form of chips, pellets and feed grade single cell protein. The cassava plant, made up of the roots, leaves and stem, is a good source of carbohydrate and protein. The different parts of the plant can be used as animal feed. The leaves can be used as silage, dried for feed supplementation and as leaf meal for feed concentrates. The stem can be mixed with leaves and used as ruminant feed, or dried for feed concentrates. The roots can be chipped or pelletized and used as feed, while the root peel, broken roots, fiber and baggase from starch extraction and garri processing can be dried and used directly as animal feed or as substrate for single cell protein production. The use of cassava root as animal feed is increasing in importance in the developing countries of Latin America and Asia where an export market for this commodity has developed [41].

2.3 Processing of Cassava into Chips and Pellets

The flow chart for this process is shown in Figure 1. There is very little difference in the technologies used at different scales of chip and pellet production. The main difference is in sun-drying and mechanical drying. Chips can be produced by very simple techniques in the household or village as well as on a large mechanized scale.

About 2.5-3.0 tonnes of fresh roots are required for 1 tonne of pellets giving a conversion rate of 33-40 %. The first step can be washing and peeling, depending on the quality of the harvested roots [42].

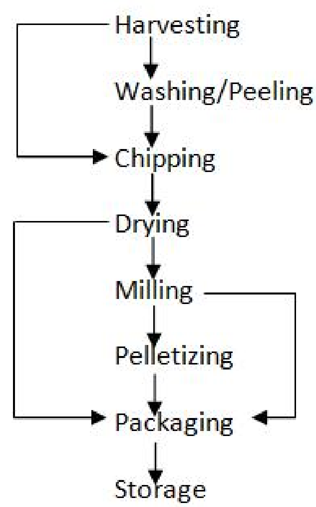

Figure 1: Flow chart for the production of cassava chips and pellets [43]

2.4 Processing of Cassava Leaves and Stems

Dried cassava leaves and stems can be fed to pigs, poultry, and dairy cattle. The meal produced from them has a nutritive value similar to that of alfalfa though deficient in methionine, isoleucine and threonine [44, 45, 46]. Cassava leaves are a good source of about 20% protein. The amount of protein depends on the stage of growth. The processing of the aerial part of the cassava plant made up of both the leaves and the stem is shown in Figure 2. For the extraction of cassava leaf protein, the leaves and the stem are interacted in a chopper or grinder and the juice pressed out.

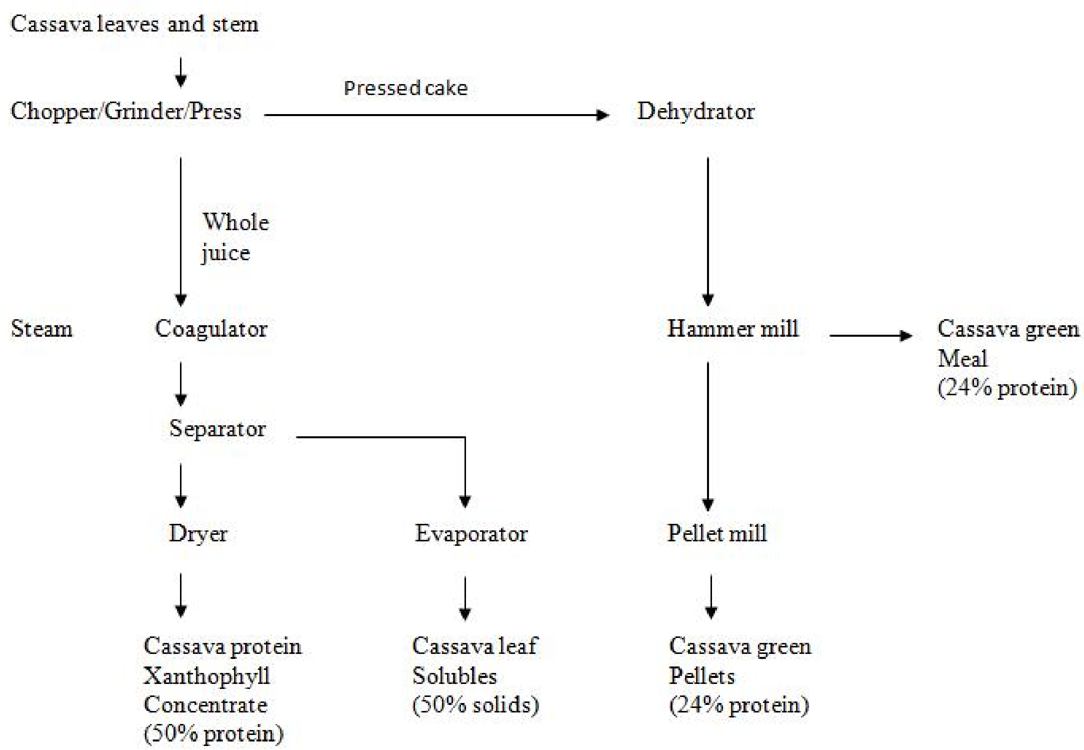

Figure 2: Flow chart for processing cassava leaves and stems [43].

The extracted juice is then coagulated with injection of steam. The pressed cake is sent to the dehydrator. The coagulated juice is then sent to a separator where the soluble fraction is separated from the green curd and moved to the evaporator where it is concentrated to 50% by volume. The curd is sent to the drier to produce the cassava protein concentrate which is 50% protein [47].

2.5 Production of Single Cell Protein from Cassava

The use of cassava as substrate for single cell protein has been investigated since the mid-1960s. Gray and Abou-El-Seoud [48] grew some filamentous fungi on ground cassava roots, supplemented with ammonium chloride and corn steep liquor, to obtain biomass containing 13-24% crude protein.

Shrassen *et al*. [49] described a process in which the yeast *Candida utilis* fermented enzymatically hydrolyzed cassava in a submerged culture to produce a product containing

35% crude protein on a dry weight basis. Gregory [50] using *Aspergillus fumigatus* 1-21 A fermented whole cassava in a nonaseptic continuous fermentation system to produce single cell protein containing 37% crude and 27% true proteins. The fungus was a nonreversible sporogonous mutant of *A. fumigatus* 1-21. This product was fed to rats and it produced good growth responses.

Single cell protein can be produced by two types of fermentation processes, namely submerged fermentation and semisolid state fermentation (Figure 3).

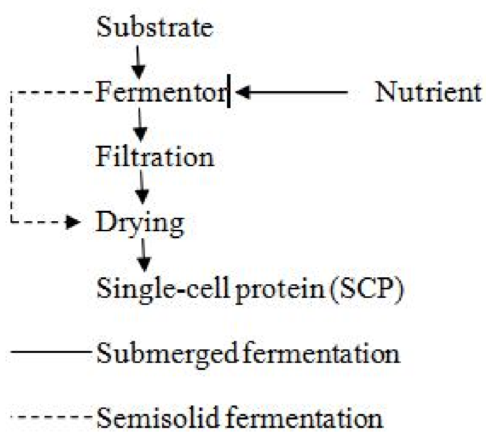

Figure 3: Flow chart for single-cell protein production [43]

2.6 Textile and Art

Starch is a textile material which can be produced from cassava. Cassava roots are peeled, washed and grated. The grated pulp is steeped for 2-3 days in a large quantity of water, stirred and filtered through a piece of cloth. The filtrate stands overnight and the supernatant is then decanted. The starch sediments are air-dried under shade. It has been discovered that sugar could be produced by the acid hydrolysis of starch [51]. Glucose, or dextrose sugar, is found in nature in sweet fruits such as grapes and in honey. It is less sweet than sucrose (cane or beet sugar) and also less soluble in water; however, when used in combination with sucrose, the resulting sweetness is often greater than expected.

Starch is produced from grain or root crops such as sweet potatoes, maize, wheat, rice, yam or cassava. The advantages of cassava for starch production over other grains or root crop includes: high purity level, excellent thickening characteristics, a neutral (bland) taste, desirable textural characteristics, is relatively cheap and it contains a high concentration of starch (dry-matter basis) [52]. Cassava starch has many remarkable characteristics, including high paste viscosity, high paste clarity and high freeze-thaw stability which are advantageous to many industries. Cassava is a renewable, an almost unlimited resource and one of the most abundant substances in nature. It is one of the most important starchy root crops of the tropics used for food and industrial purposes [53].

2.7 Starch Extraction Process

Cassava starch is been produced primarily by the wet milling of fresh cassava. The extraction of starch from fresh cassava roots follows the steps outlined in Figure 4. When cassava roots are harvested or selected for starch extraction, age and root quality are critical factors [53]. According to Akpa [53], cassava roots need to be processed almost immediately after harvest, as the roots are highly perishable and enzymatic processes accelerate deterioration within 1-2 days. Substantial amount of cassava will be peeled, washed and grated to finer particles. The starch will then be extracted from the grated pulp by sieving while the fiber will be retained. The fiber retained will then be washed repeatedly for at least three to four times with distilled water on the screen. The starch thus extracted will be allowed to sediment after which the fiber will be decanted off and the starch rewashed with distilled water to remove the remaining fiber. The starch will then be dried in an oven at a temperature of (45 ^{o}C) for six hours to reduce the amount of moisture content and finally dried under the sun for four hours.

The powdery starch produced can then be stored in an air tight container to prevent contamination and moisture.

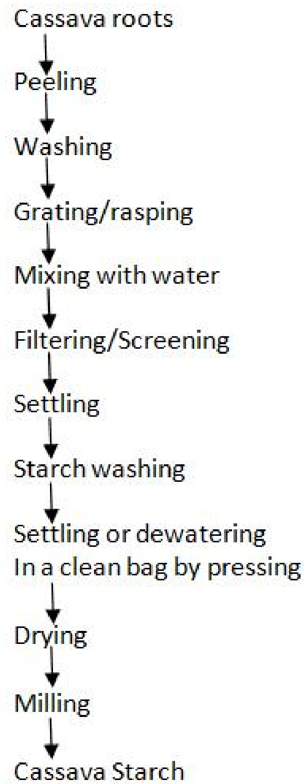

Figure 4: Flow chart for production of cassava starch [53].

Native starches irrespective of their source are undesirable for many industrial applications because of their inability to withstand processing conditions such as extreme temperature (has low thermal resistance), diverse pH and high shear rate (has low shear resistance) [54], high ability to retrograde, loss of viscosity, syneresis tendency and thickening power upon cooking yield pastes of poor stability which decreases its shelf life (storage stability) causes shrinkage and the release of water [19]. In order to improve on the desirable functional properties and overcome its limitations, native starches are often modified. The procedures involved in the production of modified starch are as given in Figure 5.

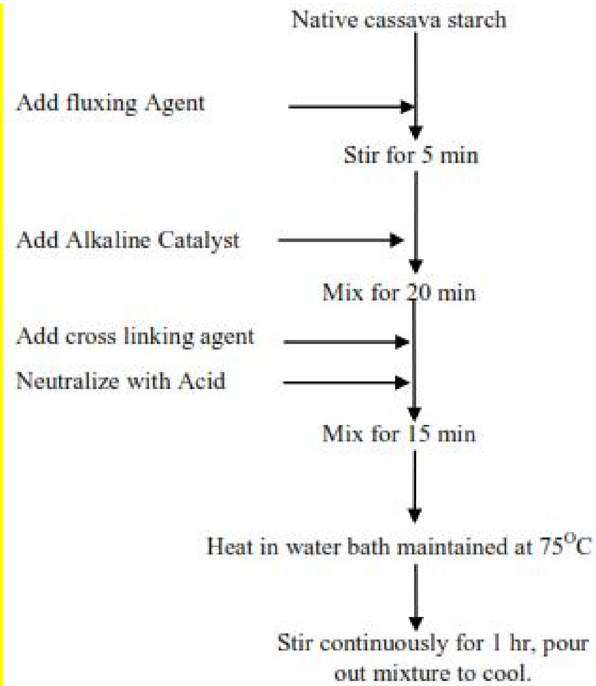

Figure 5: Flow chart for the preparation of modified cassava starch [19].

Another important industrial application of cassava cyanide compound is in the production of adhesive. Cassava based adhesives have the unique advantage of having smooth, clear fine texture, non-staining, more viscous, stable and neutral pH [53]. The nonpoisonous nature makes it a desirable choice particularly for domestic and most non-structural utilization [52]. The procedure for the production of cassava based adhesive is presented in Figure 6.

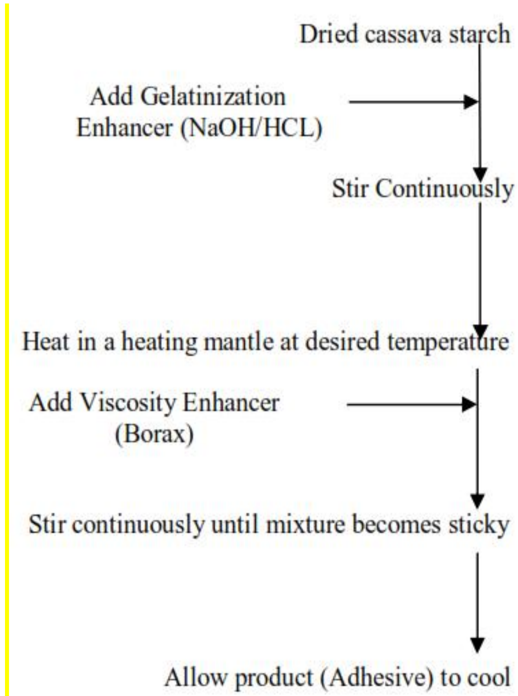

Figure 6: Flow chart for the preparation of Adhesive [53].

2.8 Gold Extraction using Cyanide from Cassava Solution

Cyanidation is a process for the extraction of gold from ores using cyanide solution and was first developed by MacArthur Forrest [55]. Since then, it has become the principal method of extracting gold from ores. In this process, the ore is crushed to a very fine powder. Such powdered ore is heaped onto open-air leach pads put on a base of asphalt or impervious plastic sheeting. A dilute solution of cyanide, usually sodium cyanide, is sprayed through sprinklers on the heap. The cyanide solution percolates down through the heap for several weeks, forming cyano gold complexes. This solution, enriched with gold, gets collected at the bottom into the pond termed pregnant pond, from which it is pumped to the recovery plant. In the recovery plant, the solution containing cyano-gold complex is filtered off and the remaining rock pulp is separated [17]. Zinc dust is then added to the solution containing cyano-gold complex to reduce the gold (III) oxidation state to zero oxidation state (metallic state). Gold is thus precipitated out as a high grade concentrate. Gold precipitate is then refined to get high purity gold. The perfection of the cyanide process largely replaced amalgamation process [21]. This has proved to be an economical process even for the extraction of gold from low grade deposits in spite of the low recovery (60% - 70%) of gold. The method is preferable to amalgamation because the spent cyanide solution discharged as effluent is biodegradable [17, 21].

2.9 Pack-Cyaniding using Cassava Leaves

Pack-cyaniding of mild steel using cassava leaves and the characterization of the case formed have been reported [9, 10]. Cassava contains some amount of cyanide that is often removed as waste during processing. Researchers have devised means of converting this wanton cyanide waste to engineering value via a clean technology technique thereby making it of benefit to human use [18, 20].

Fresh cassava leaves of specie *Manihot esculenta (bitter local variety)* were collected, oven-dried, pulverized and subjected to sieve analysis to produce the required particle size. Required particle sizes are mixed with $BaCO_3$ salt by combining 4 volumes of cassava powder with 1 volume of $BaCO_3$ Salt [18]. A firm fireclay luting is provided at the slits between the cyaniding boat and its cover plate. Mild steel sample completely embedded in the cyaniding boat is loaded into a muffle furnace at room temperature. The furnace is heated to 950 ^oC and held for sufficient time depending on the sample thickness and case depth required [18]. The samples can then be cooled in air or quenched in water/oil as the case may be. This process is called high temperature pack-cyaniding. The process is the same for low temperature pack-cyaniding except that the energizer is now $BaCl_2$ salt and heat treatment temperature is 550^oC.

3.1 Cyanide Compounds and Chemical Transformations

Cyanogenic glycosides are produced naturally by many plants; when hydrolyzed, they produce hydrogen cyanide. Chemical structures of some commonly occurring cyanogenic glycosides are depicted in Figure 7.

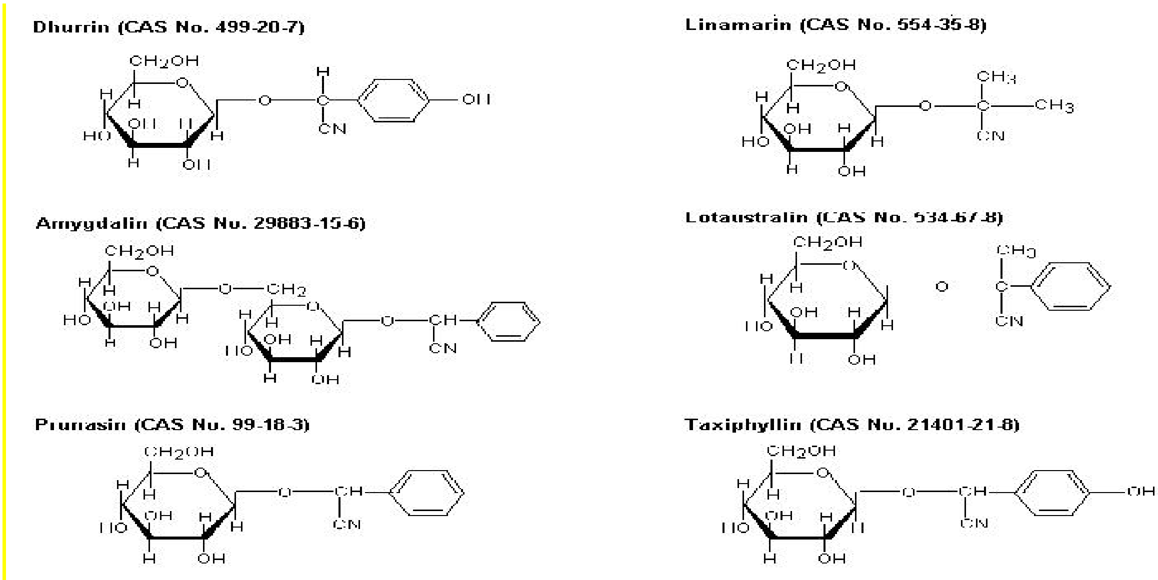

Figure 7: Cyanogenic glycosides in major edible plants [56]

Amygdalin occurs in almonds, dhurrin in sorghum, linamarin in cassava, lotaustralin in cassava and lima beans, prunasin in stone fruits, and taxiphyllin in bamboo shoots.

3.2 Chemical/biochemical Transformations of Cyanide Compounds

Hydrogen cyanide can be produced by hydrolytic reaction catalyzed by one or more enzymes from the plants containing cyanogenic glycosides when the seeds are crushed and moistened. Amygdalin (which is also present in cassava, bitter almonds, and peach stones) is converted to glucose, benzaldehyde, and hydrogen cyanide (Figure 8) [57]. Hydrogen cyanide release can occur during maceration, which activates intracellular *beta*-glucosidases. This reaction can also result from chewing, which causes the enzyme and the cyanogenic glycosides stored in different compartments to combine [28, 58]. The reaction occurs rapidly in an alkaline environment, and the hydrolysis is complete in 10 min. Hydrolysis is possible in an acid solution but it takes place slowly.

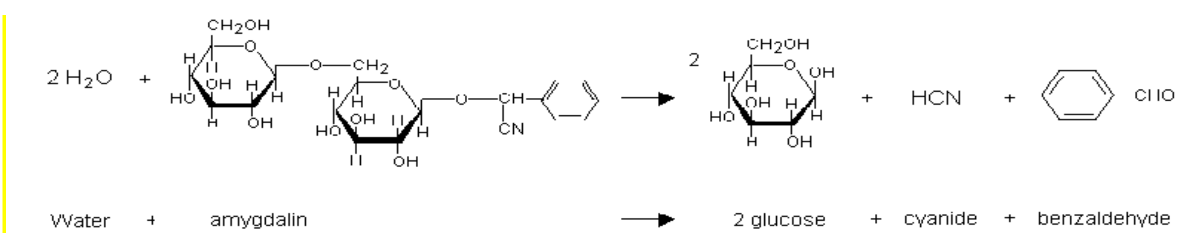

Figure 8: Hydrolysis of amygdalin [59]

Liberation of hydrogen cyanide from cyanogenic glycosides occurs usually after ingestion and hydrolysis by the glycosidases of the intestinal microflora and, to a lesser degree, by glucosidases of the liver and other tissues [60].

When the tissues of the cassava leaves are mechanically damaged by pulverizing, hydrolysis reaction then takes place, evolving hydrogen cyanide (HCN) as shown in the reaction in Figure 9:

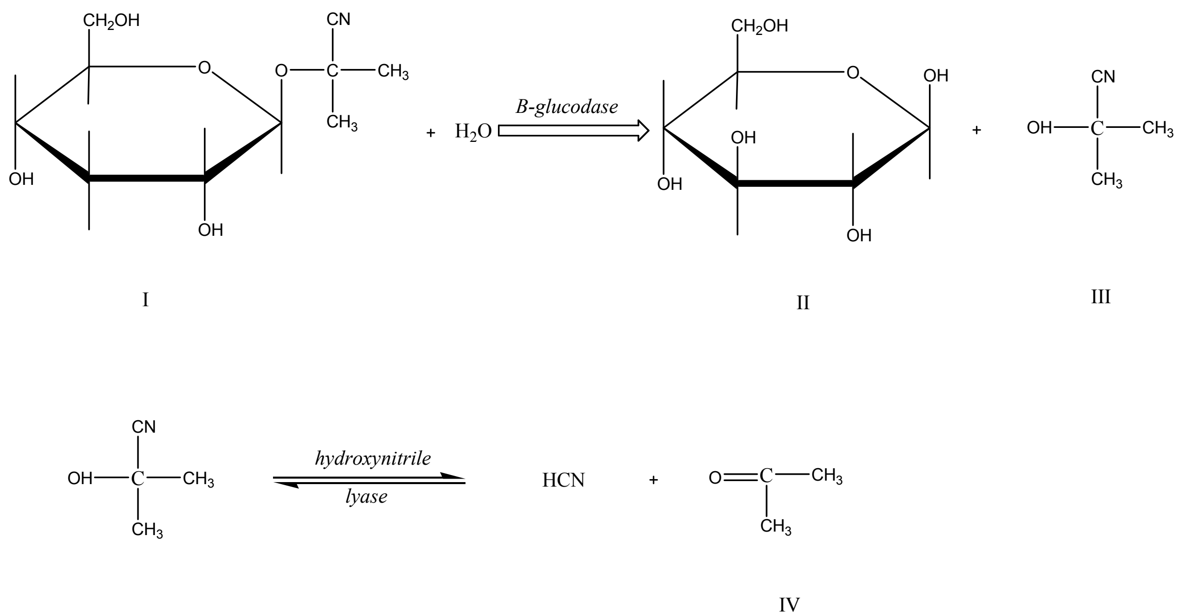

Figure 9: The mechanism of enzymatic decomposition of Linamarin [11, 24].

(I-Linamarin, II- glucose, III-acetone cyanohydrins, IV- acetone)

3.2 Metabolism of Cyanide

Cyanide can react with substances such as methaemoglobin in the bloodstream, but the majority of cyanide metabolism occurs within the tissues [59]. Cyanide is metabolized in mammalian systems by one major route and several minor routes. The major route of metabolism for hydrogen cyanide and cyanides is detoxification in the liver by the mitochondrial enzyme rhodanese, which catalyses the transfer of the sulfane sulfur of thiosulfate to the cyanide ion to form thiocyanate (Figure 10) [61, 62]. The rate determining step is the amount of thiosulfate.

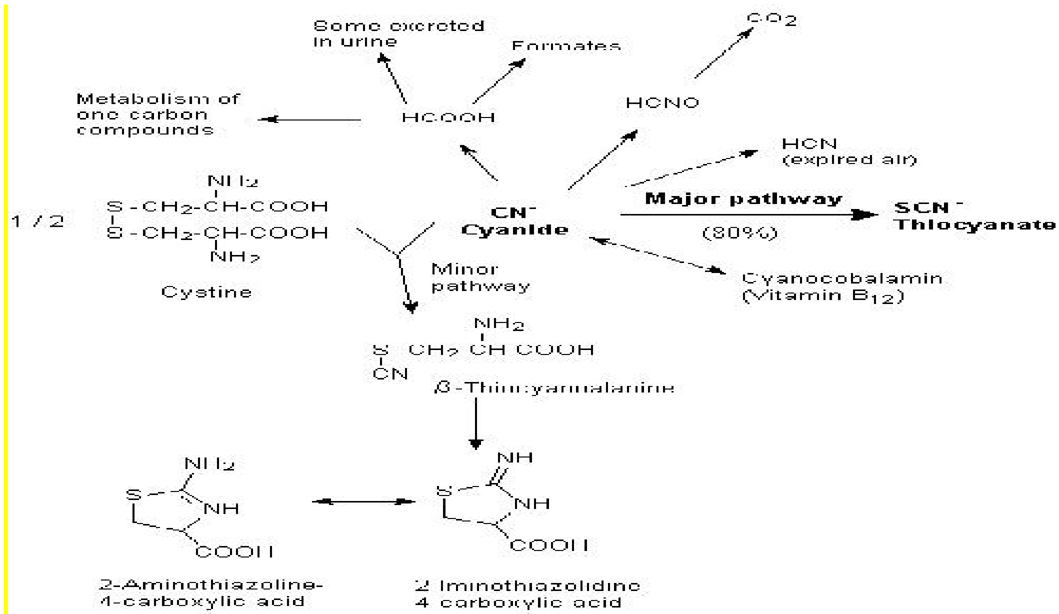

Figure 10: Basic processes involved in the metabolism of cyanide [63].

4.0 DISCUSSION

Cassava is one of the most important food crops grown in the tropics [43] and a significant source of calories for more than 500 million people world-wide. The production of cassava for human consumption has been estimated to be 65% of cassava products, while 25% is for industrial use, mostly as starch (6%) or animal feed (19%) and 10% lost as waste [41]. The production has significantly improved with Nigeria as the largest producer and garri as the most consumed and traded of all the food products from cassava roots in Nigeria [64] and in many other countries in West Africa. It is creamy-white, partially gelatinized roasted free flowing granular flour. Its wide consumption is attributed to its relatively long shelf life compared to other food products from cassava, as well as its ease of preparation for eating.

Cassava is a major raw material used in many industries in Thailand. It is used in the production of Monosodium glutamate and other amino acids, sweeteners, ethanol, etc. Large cassava wastes are obtained from these production processes (containing a high amount of starch) and are used mainly as animal feed. These cassava wastes can still be utilized to produce ethanol due to its content of cellulose and hemi-cellulose at levels of 24.99 and 6.67 % (by weight) respectively [65]. The use of cassava waste as raw material in ethanol production not only reduces waste material created from the cassava starch industry, but also lowers the cost of ethanol production [66]. Presently, more than 60% of cassava produced in China is used for industrial purposes, 30% is used for animal feed and only 10% is used for human food [67].

Starch is one of the most important but flexible food ingredients possessing value added attributes for innumerable industrial applications [19]. The most common sources of food starch are corn, potato, wheat, cassava/tapioca and rice. Cassava is second only to sweet potato as the most important starchy root crop of the tropics [67]. It is now grown widely as food crop and for industrial purposes. Cassava is particularly suitable for production of modified starch. Modified starch is a main product among starch derivatives because it has become a new raw material in multiple industries. For example, modified starch is the third most important material in the paper making industry, and large amounts are also used in the textile industry [68].

Production costs are lower for cassava than for alternative food staples. Available farm management data indicate that labor constitutes 80 percent or more of production costs in smallholder cropping systems in Nigeria. Cost of production per metric ton (MT) is lower for cassava when compared with alternative food staples [10].

The pre-process storage is the main problem of cassava utilization on an industrial scale. Physiological deterioration occurs in cassava roots 2-3 days after harvesting, followed by microbial deterioration 3-5 days thereafter [5]. This deterioration is either primary deterioration, which is characterized by the discoloration of roots or microbial deterioration.

The starch also undergoes structural changes. Economically, the roots discoloration is more important than the microbial deterioration because it reduces the economic value of the roots and most especially for production of gari and fufu [31].

Several modern storage methods have been developed to control the deterioration like refrigeration, freezing, waxing and chemical protection. While the traditional methods include leaving roots in the soil after maturity, burial of freshly harvested roots, storing in trench etc. However, most of the modern methods may not be economically viable for storing of cassava roots prior to processing to major products like gari and fufu [64].

At present most of the dextrose in commerce is prepared in the form of pure dextrose monohydrate by a combined acid-enzyme process. The hot, thick glucose syrup with a concentration of 70-80 percent dextrose is run from the evaporator into crystallizing pans. Crystal formation is largely controlled by the quantity of dextrins left with the glucose. The separation of crystals from the syrup is carried out in centrifugal separators and the impurities are left in the mother liquor. Crystalline dextrose is then dried in rotary hot-air driers under vacuum and bagged in moisture-proof materials [67; 69].

Recrystallization of dextrose will yield practically 100 percent pure dextrose crystals which are used as a pharmaceutical-grade sugar [67].

The starch used in the manufacture of glucose syrup must be as pure as possible with low protein content (particularly soluble protein). In this respect, cassava starch can be preferable to other starches [67].

There is an increasing interest in manufacturing glucose syrup directly from starchy roots or grains rather than from the separated starch in order to save on capital investments for the production and purification of starch from such raw materials.

The starch conversion industry (glucose and dextrose) is the largest single consumer of starch, utilizing about 60 percent of total starch production. Glucose syrup and crystalline dextrose compete with sucrose sugar and are used in large quantities in fruit canning, confectioneries, jams, jellies, preserves, ice cream, bakery products, pharmaceuticals, beverages and alcoholic fermentation [67].

The functional purpose of glucose and dextrose in the confectionery industry is to prevent crystallization of the sucrose; in the bakery products industry it is to supply fermentable carbohydrates; and in the ice-cream, fruit-preserves and similar industries it is to increase the solids without causing an undue increase in the total sweetness, thus emphasizing the natural flavour of the fruit, and also to prevent the formation of large ice crystals which mar the smooth texture [67]. In general, glucose and dextrose are used in the food industry as a partial or complete substitute for sucrose. The use of dextrose has increased in recent years in the food-processing industries.

Surface strengthening processes of carburizing, nitriding, carbonitriding, cyaniding, etc, in order to have materials treated for service properties require the use of expensive reagents, most of which are currently being imported into Nigeria. Thus most of the components fabricated locally hardly go through these post-fabricated treatments, leading to frequent replacements of such components. The conventional mode of cyaniding involves the use of the salts of the cyanides and cyanates which are very toxic. The present process, which makes use of waste cassava peels and leaves, reduces the toxic impact of cyaniding on the personnel as well as the environment [18]. In addition, the process utilizes waste and converts it to wealth thus affording cost savings to consumers thereby promoting local content initiatives. The major drawback of cyaniding is the poisonous nature of cyanide and the process is only applicable to low carbon steel materials. In small and medium scale enterprises, salt bath treatment is the commonest method probably because of its relatively low cost and reduced treatment time. Unfortunately, substantial amount of highly toxic, corrosive and environmentally unfriendly gases are liberated from the fused salt mixture into the atmosphere. The disposal of the spent salt mixture is also hazardous to both the flora and fauna of the environment. Liquid salt bath nitriding in cyanide-cyanate baths tends to release toxic greenhouse gases like CO, CO_2, HCN, HCl and so on into the atmosphere. Both the salt composition and by-products are very toxic [18].

In 2007, cassava is Thailand's second most important crop after rice and the third biggest agricultural export after rubber and rice FAOSTAT [70]. Uniquely in Thailand, cassava is grown as an industrial rather than a staple crop. The Thai cassava industry is highly export-oriented, with 66 percent of total production in 2008 exported, 26 percent utilised domestically and the rest kept as stock TTSA [71]. The industry consists of two main value chains: the dried cassava and the starch value chain (Figure 11).

The dried cassava value chain comprises of two main products. The first is chips, which are sundried pieces of crudely cut cassava roots. Chips have three main markets. They are used directly in domestic animal feed industry.

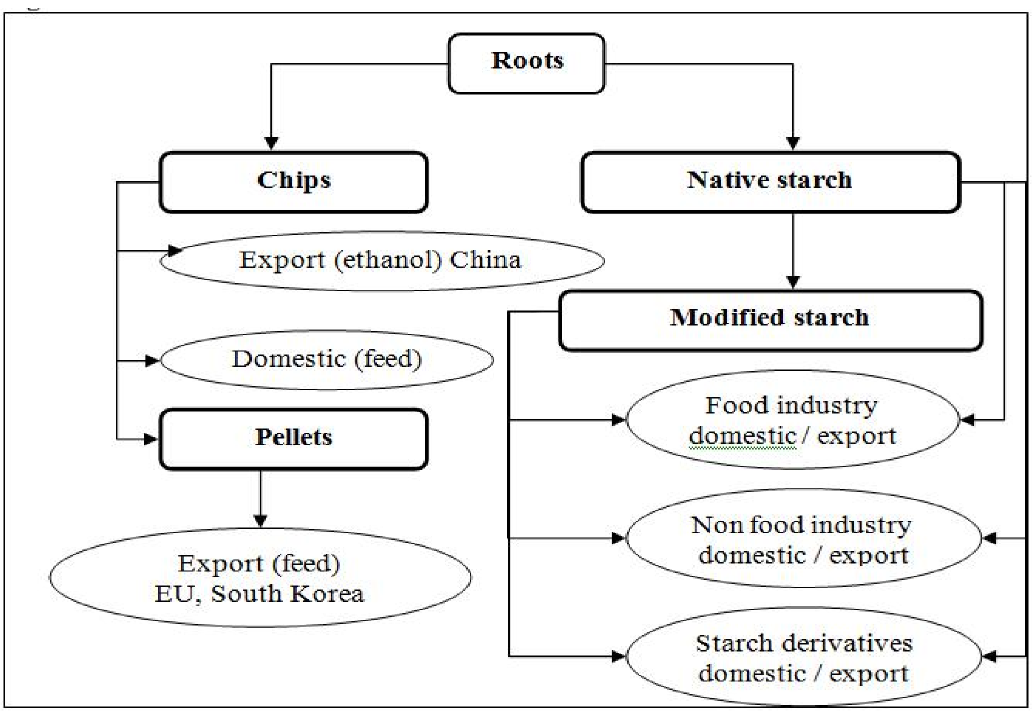

Figure 11: The Thailand Cassava Value Chains Tijaja [72]

They are exported to China where they are used in ethanol production. Lastly, they are used as intermediate inputs in pellets production, which are in turn used in animal feed production. The second product is pellets. Pellets are made out of chips and/or the waste from starch processing. To make pellets, chips are first ground and steamed, perhaps mixed with starch waste, and moulded into cigarette-shaped articles. Pellets are then mixed with other feed ingredients to make compound feed, for use in developed markets or in large commercial farms.

The starch value chain also comprises of two main products: native and modified starches. Both types of starches are used in various food and non food industries i.e. sweeteners, paper, textile, pharmaceuticals, plywood etc, with modified starch feeding into more technologically-intensive ones.

There are 25 cassava processing factories currently in operation in Vietnam with a total installed capacity to process about 1.2 – 2.0 million tonnes of fresh roots per year (60 – 80 % of cassava production). New high-yielding cassava varieties such as KM60, KM94 and KM98, and more sustainable production practices have increased the economic effectiveness of cassava production Pham *et al.* [73]. Some exciting cassava products were shown in the appendix.

5.0 CONCLUSION

This review study concludes as follows.

1. Cassava (plant and products) has both agricultural and engineering value
2. Cassava plant contains cyanogenic glucoside which produces toxic cyanide by enzymatic action
3. Earlier research efforts concentrated on reducing the cyanide content thereby diminishing the engineering value of cassava

4. Current research efforts have unveiled a vast number of engineering applications for the toxic cyanide content present in cassava (especially in the leaves and tuber bark)
5. A large number of cassava wastes are now being harnessed via a waste-to-wealth clean technology process to create engineering values
6. The following are some of the ongoing research works on the engineering applications of cassava in our laboratory:

i. Synthetic isolation of cyanide from cassava – Conversion of cyanide to metallic salt
ii. Formulation of organo-stabilized pack-cyaniding powder and pellets
iii. Advanced Materials Production – Production of gold nanoparticles

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APPENDIX

Cassava vegetation

Cassava tubers

Dried cassava chips

Premium cassava residue

Tapioca/cassava starch

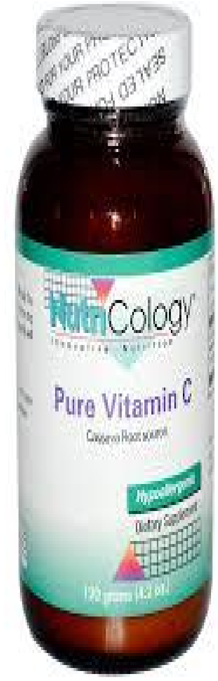
Cassava flour

Grated cassava

Tapioca Starch

Tapioca/Cassava pearls

Cassava Biomass



Made from cassava roots

Bio-degradable disposable food packages made from cassava

Cassava cake

Sources: https://encrypted-tbn1.gstatic.com/images?