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The potential of cassava and its by-products: A review

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Abstract
Cassava (*Manihot esculenta*) is a potential source of carbohydrates used to prepare various foods. This synthesis aims at taking stock of the research carried out on cassava as well as its derived products in view of a valorisation. Cassava is the most important staple food after maize and contributes to food security. It therefore provides 70-80% of the total calories consumed by humans and allows the poor to face starvation, especially during lean periods. Because of its high perishability (70% water content) and the lack of adequate fresh-keeping techniques, cassava is processed in various forms within 72 hours of harvest. It is used in the manufacture of about twenty derivatives, the main ones being gari, tapioca, boiled cassava, cossettes and also agbeli klaklou. Cassava, like other roots and tubers, is predominantly carbohydrate-rich and the dry matter content of the roots varies according to the medium, variety, temperature and age of the plant.

Keywords: cassava, food safety, perishability, manufacture

Introduction

The economies of the African countries in the South of the Sahara, of which Benin, is mainly based on agriculture which occupies a place of choice (Zannou *et al*., 2015) [55]. This sector accounts for 70% of the active population and accounts for 39% of the gross domestic product (GDP), provides 90% of the country's export earnings and contributes 15% to government revenue (APRM 2010). In Benin, the main species of roots and tubers grown are cassava and yam (IFAD, 2010). The manioc known as *Manihot esculenta* is a perennial shrub with vegetative propagation that is generally grown in tropical regions (Jekayinfa and Olajide 2007) [27]. Like other root crops, cassava plays an important role in food, both for food security and for multiple commercial and industrial uses (Biaou *et al*., 2006, Somendrika *et al*., 2016a) [9, 49]. It is the third largest food calorie source in the tropics, behind rice and maize (FAO, 2008, Somendrika *et al*., 2016b, Bahati-Kavange, 2017) [18, 50, 5]. It accounts for about 47% of the total agricultural speculation and 54% of the national production of roots and tubers (Djoï *et al*., 2003). This preponderance of cassava production can be explained in particular by the diversified range of products derived from its processing as well as the benefits that can be derived from it by improving its food and nutritional quality.

The APRM estimates that 70% of production will be processed into various by-products by artisanal and semi-industrial methods (APRM, 2010). This high conversion rate is due to the perishability of the tubers, which deteriorate 3 to 4 days after the harvest (Bell *et al*., 2000, postponed by Grandval, 2012) [6, 8, 20], taking into account their water content, which varies between 51 and 71%. Okezie and Kosikowski, 1982 [40]. As a result, processing, which provides foods with a long shelf life and adds value to the local level, appears to be a means to minimize post-harvest losses (Phillips *et al*., 2004, Somendrika *et al*. 2017) [43, 47]. The resulting range of products is diverse, including gari, fufu, lafun, tapioca, attiéké, cassava chips, cassava flour or starch (Traoré, 2008). In addition to these products, we also have cassava cakes (agbéli klaklou in fon) a product highly valued by the populations. The agléli klaklou is a product made from pressed cassava, seasoned, shaped and fried in palm or peanut oil. Although imported food is of great importance in urban areas, there is a strong demand for local food products, but these are less accepted because of quality and safety issues (Sanni *et al*., 2007) [45]. The objective of this synthesis is to review the research work on cassava and its by-products for an improvement in processing technologies.

Origin and cultural expansion

Some authors attribute a tetraploid origin to cassava belonging to the Euphorbiaceae family. According to Silvestre and Arraudeau, 1983, cassava, commonly known as Manihot esculenta crantz in French-speaking Africa, originated in South America. It was introduced into Africa by the Portuguese towards the middle of the 16th century. Originally broadcast in Central Africa, it was only reported in West Africa towards the end of the 17th century. It is predominantly found in densely populated areas of tropical forests and savannas (Carter *et al*., 1992). In Asia, cassava would have been introduced directly from Mexico to the Philippines, and indirectly from the Mascarene Islands via Ceylon (1786), India (1794) and Southeast Asia. In Africa, precisely in the former Belgian Congo in 1949, cassava was quickly known and appreciated by the local population and gradually took the place of the various starchy crops or crops, to the point that at present it is, together with bananas, the basic hydrocarbon food of most Congolese. It is now grown throughout the tropics (Purseglove, 1987) [44].

Characteristics of cassava

The plant is interesting from its edible roots. Cassava is a shrub, semi-woody, reaching in cultivation 2 to 3 meters in height. The crop is multi-annual, but generally grown as an annual or biennial plant like all euphorbiaceae, its various parts contain latex. The root system of cassava is well developed and gives it a good tolerance to drought. In addition, the efficacy of the scalp is enhanced by the presence of endomycorhize (a symbiotic association of roots with a growing fungus in earlier root tissues). The main roots tend to be tuber. These roots, rich in starch, are arranged in bundles and measure 30 to 80 cm in length and 5 to 10 cm in diameter. Their weight usually varies from 1 to 4 kilograms. Under certain circumstances they can reach 1 meter in length and weigh 20 to 25 kilograms. They have a brownish or reddish bark. The fiber content increases with age. The stems, the diameter of which does not exceed 2 to 4 cm, are largely filled with marrow and, as a result, very fragile as long as the abutment is incomplete, the leaves are arranged in a spiral according to a phyllotaxy of and characterized by multiple foliar lobes (usually five lobes sometimes three or seven) of various shapes. The color of the leaves, sometimes purple in young age, is light green to dark green. The leaves are carried by petioles 5 to 30 cm. Cassava is a mosaic plant. The inflorescence is a terminal raceme with unisexual flowers. Female flowers are used at the base of the racemes and are pink, purple, yellowish or greenish in color. They are devoid of corolla, the male flowers are located at the top of the inflorescences. Within the raceme, the flowering of the male flowers is delayed by one week compared with that of the female flowers (prologynia) favoring cross-pollination by insects. The fruits are dehiscent capsules with three lodges bursting loudly at maturity each releasing a seed. The seeds are ellipsoid, 10 to 12 mm long, and characterized by a well developed capsule, typical of the euphorbiaceae family.

Botanical classification and description

Cassava Manihot esculenta (Assiedu, 1991) is a dicotyledonous angiosperm phanerogam belonging to the family Euphorbiaceae. The Euphorbiaceae family contains more than three hundred genera and eight thousand species, almost all tropical. The manioc, Manihot esculenta Crantz, Dicotyledon of the family Euphorbiaceae is a shrub of 1 to 5 meters in height, cultivated in tropical region for its tuberated roots. Its cultivation area covers various ecological zones (Table 1). The root is low in protein, but has a starch with excellent digestibility (Silvestre and Arraudeau, 1983); the leaves, also consumed, constitute an important nitrogen supplement (Table 2). Cassava is a cyanogenetic plant (De bruijn, 1971), "soft" varieties of "bitter" varieties are classically distinguished in relation to their hydrocyanic acid (HCN) content. High-grade varieties must be detoxified before consumption (processing techniques are based on drying, roasting or rooting).

Production of cassava

Cassava lends itself to polyculture, supports drought and infertile soils (Ceballos *et al*., 2006) [11]. Its ability to remain in the soil two to three years after maturation gives it interesting characteristics (Kehinde, 2006) [28].

Composition and Uses of Cassava

Leaves

Raw cassava leaves contain considerably more energy, proteins, lipids, carbohydrates, fibers, ash, mineral salts (Ca, P, Fe, etc.), vitamin A, thiamine, riboflavin and niacin than certain introduced vegetables, such as Chinese cabbage or spinach (IITA, 1990) [26]. Cassava leaves are particularly rich in essential amino acids (isoleucine, leucine, lysine, methiomine and cysteine, phenylalanine and tyrosine, threomine, tryptophan, valine). The levels per 100 g of leaves are sufficient to cover the daily needs of humans as recommended by FAO and WHO (World Health Organization). Like roots and all other parts of the plant, cassava leaves also contain high cyanogenic glucosides (20 mg / 100 g on average) which must be neutralized by slicing, crushing and boiling leaves between 15 minutes and an hour. However, it is necessary to avoid cooking too long which would lead to a degradation of the vitamins. In order to improve cyanogen reduction, water can be changed during cooking (http://www.fao.org/impho/)

Roots

The root, the most exploited part, is essentially rich in carbohydrates with low fat contents. These levels vary with the variety, locality, age of the crop harvested and environmental conditions (Balagapolan *et al*., 1988) [6]. According to Okezie and Kosikowski, 1982 [40], the water content of manioc roots varies between 51 and 71%; that of sugars, between 30 and 35% and proteins between 0.6 and 2.6%. These authors noted a small amount of vitamins and minerals and stated that cassava starch had a low amylose content of about 17% compared to potato starches (22%) and maize (21%). Cassava proteins are rich in arginine and low in certain essential amino acids such as methionine, lysine, tryptophan, phenylalanine and tyrosine (Falade *et al*., 2010). However, overall, the nutrient intake of cassava is considerable in that it is high in calories and can therefore be very useful during lean periods (Diallo *et al*., 2013) [15]. The following table gives the nutritional composition of the leaves and roots of cassava according to several authors.

Table 1: Nutritional composition of cassava leaves and roots.

	Leaves	Roots				
	A	A	B	C	D	E
Dry matter (%)	-	-	28,5	35	30 - 35	-
Water (%)	80	62 - 68	-	-	-	51 - 71
Carbohydrates in% of MS	7	35	94,1	89	61,42 - 71,66	30 - 35
Lipids as% of MS	1	0,3	0,45	1	2 - 3,66	-
Protein in% of MS	6	env. 1	2,59	2,5	1,2 - 1,4	0,6 - 2,6

Fiber in% of MS	-	-	0,42	4,5	3,14 - 3,66	-
Ash as% of MS	-	-	2,42	3	1,54 - 1,8	-
Vitamin C (mg / 100g)	200	35	-	-	-	-
Vitamin B1 (mg/100g)	0,2	negligible	-	-	-	-
Vitamin B2 (mg/100g)	0,3	negligible	-	-	-	-

Sources: A : Onwueme, 1978 ; B : Akinrele *et al*., 1962 ; C : Silvestre et Arraudeau, 1983 ; D : IITA, 1990 [25] ; E : Okezie et Kosikowski, 1982 [40] - : Not determined

Toxic substances and antinutritional factors of cassava

Despite its nutritional importance, cassava has a major disadvantage that limits its use in human food. This is toxicity due to the presence of two cyanogenetic glucosides: linamarin (93 to 97%) and a small amount of lotaustralin (3 to 7%) (Stupak *et al*., 2006; Cumbana *et al*. 2007) [51, 13]. Research has yielded very innovative results in the mechanisms of reduction of cyanogens during processing (Sanni and Jaji, 2003; Aerni, 2004) [46, 2]. Because the cyanogen content of the leaves is high (up to 20 times that of the roots), they require careful processing to become edible. If the previously chopped leaves are cooked for 15 minutes, about 85% of the cyanogens are removed. If the leaves are crushed or crushed, nearly 97% of the cyanogens are neutralized (Bell *et al*., 2000) [6, 8]. The following table provides a comparative overview of the effectiveness of some processing techniques in terms of the removal of cyanogenic glucosides from untreated commodities. The table shows that unprocessed foodstuffs are far from meeting the FAO/WHO standard (10 mg HCN/kg maximum), but also that most treatments result in always high levels. Only the drying in the sun and the retting followed by a baking meet the norm. Cases of food poisoning, rare but sometimes fatal, have been reported in Vietnam, Mozambique, Angola and Zaire. They occur in populations that feed exclusively on bitter manioc, in times of civil strife or shortage, and who are unaware of the need to transform it. In practice, prolonged food cooking is sufficient to eliminate residues of hazardous cyanogens (Bell *et al*., 2000) [6, 8].

Table 2: HCN content of various products of cassava processing.

Food	Method of transformation	HCN content (mg equivalent / kg)
Leaves	Sans traitement	420
	Hachage + cuisson	60
	Broyage + cuisson	15
Roots	Without treatment	112
	Sun drying	3,5
	Artificial drying	13
	Routing for 3 days	19
	Routing + couking	1,5
	Routing + drying	16
	Production of gari	6
	Production of fufu	10 à 25

The different varieties of cassava

The criteria for differentiating varieties of cassava are very variable and the easiest to identify are the morphological characteristics. What is important for cassava producers is the dry matter content of the variety, its yield and the quality of its by-products. There are varieties of which the flesh of the tubercle is sweet, and others which have a bitter flesh. The bitterness is related to the release, during an injury, of hydrocyanic acid, a compound produced by the enzymatic hydrolysis of two cyanoglucosides, linamarin and lotaustralin. They are usually found to be 95% for linamarin and 5% for lotaustralin (Mcmahon *et al*., 1995) [34].

Predators of cassava cultivation

In Benin, crops are prey to attacks by harmful animals and plants and yields are falling. These predators cause damage from defoliation to complete plant destruction, causing huge losses to producers. To overcome these predators, the emphasis is now on the use of large quantities of herbicides, insecticides and chemical fertilizers (Aikpo *et al*., 2016); which could be a source of contamination.

Storage and conservation of cassava

The high water content of cassava makes it an extremely perishable commodity. Thus, cassava roots begin to deteriorate 3 to 4 days after harvest (Grandval, 2012) [20]. They are then subject to two types of deterioration (Brabet, 1994) [10]:

The first deterioration is physiological and is manifested by the appearance of dark blue stripes on the periphery of the central cylinder;

- The second so-called pathological or microbial deterioration is characterized by the invasion of the microorganisms, thus causing the root to rot. These deterioration leads to softening of the root (Eggleston *et al*., 1992) [16].

The physiological deterioration would be due to the plant's responses to the wounds. The initial response is an occlusion of the xylem vessels, followed by the production of phenolic compounds in the reserve parenchyma. The secondary response comprises: increasing the activity of phenylalanine aminolyase, peroxidases and polyphenols oxidases and the formation of polyphenols; which often slows the formation of the periderm on the wound (Cooke *et al*., 1983).

Pathological deterioration is mainly due to fermentation reactions caused by fungi, yeasts and bacteria that invade the roots (Linnemann, 1981) [31]. Their activity is more important in humid environments. Thus, storage under high humidity conditions, while effective in preventing vascular discoloration, will only allow good root conservation if measures are taken to avoid invasion and microbial activity after harvesting (Wickham, 1988) [54].

Conservation of cassava is therefore difficult and delicate and involves many traditional and improved techniques. The main form of conservation in many areas is to leave cassava underground and harvest it as needed. However, this method does not permit the continued exploitation of the land which is thus occupied by mature crops that could have been harvested (IITA, 1989) [26, 29]. This method also promotes losses due to the attack of rodents. In addition, the roots become more fibrous and more lignified; which decreases their starch content (Kwatia, 1986) [29]. Herath (1979) [22] reported that cassava roots can be conserved for 2 months with acceptable levels of loss in straw-covered pits covered with soil. Other techniques such as root packing in a place with daily watering, soaking roots in the mud, storage in sawdust or wet wood chips are also used. But the shelf life is only extended by a few days. To overcome this problem, improved techniques have been designed and tested. Thus, roots can be packed in polyethylene bags after fungicide treatment. Tiky-Mpondo (2001) [52] reported that conservation of cassava roots by using low temperatures (6, 9 and 12 ° C) increases the shelf life of cassava from 7 to 10 days without any alteration. Modern techniques such as freezing, g-ray irradiation and controlled atmosphere storage were tested. But these techniques, while effective, are very expensive especially for small producers (IITA, 1989) [26, 29].

Products derived from cassava

It is rare to find a foodstuff that can undergo as many transformations as cassava and is eaten in such diverse forms. Due to the diversity of processing techniques and the resulting products, the ways to consume cassava vary widely in different regions of Africa. This leads to various products, which are consumed immediately or stored (HAHN, 1989) [21]. Cassava is grown for food, feed and industry (Adjanohou and Allagbé, 2011) [1]. For Nwokoro *et al*., 2002 [39], more than 2/3 of the total cassava production is used for human consumption.

Human food

According to Lancaster *et al*. (1982) [30], cassava is consumed in various forms: raw, cooked or processed. In Africa, the products derived from the processing are varied and differ according to the areas: chips, raw meal, gari, tapioca, etc. Some are commonly eaten in more than other countries: the attiéké in Côte d'Ivoire, the gari in Benin, the fufu in Ghana, the Chikwangue in Congo, the flour in Nigeria (Diallo *et al*., 2013) [15]. A review of the evolution of the inventory and evaluation of traditional food technologies revealed the existence of about 20 foods produced from cassava with gari as the predominant food (Hounhouigan *et al*., 1996). The following table summarizes these products.

Table 3: Traditional cassava-based foods in Benin (Hounhouigan *et al*., 1996)

Aliments non fermentés		Aliments fermentés
1. Cossettes de manioc	10. Fingnin	19. *Gari*
2. Kuté libo	1l.Galikponnon (pain de manioc)	20. Fufu
3. Farine de manioc	12. Goman (amidon)	21.Lafun
4. Ayan (Purée de manioc)	13. Goman kluiklui (snack)	22. Attièké
5. Kuté dida (manioc bouilli)	14. Kponnonvi (biscuit de goma)	23. Agléli mawè
6. Kuté mime (manioc grillé)	15. Tapioca (amidon granule)	
7. Kuté siso (manioc frit)	16. Abloyoki	
8. Kutéta (snack)	17. Kuté founfouin (manioc pile)	
9. Agbéli klaklou	18. Greedy (goma séché au four)	

According to Nago and Hounhouigan (1989) [38], the main cassava processing products can be grouped into three categories: raw, intermediate and elaborate products.

The gross

They gather the prepared manioc roots***:***

- «*Fingnin dida*» or boiled cassava

The peeled roots of cassava are boiled in water until softened and are usually consumed with palm oil or frying. They can also be crushed and eaten with sauce.

«*Fingnin siso*» *or fried cassava*

Some friable varieties of cassava are well suited for the preparation of French fries, as in the case of potatoes. The peeled, washed roots are cut, salted and then fried in oil. Cassava fries are usually eaten alone, or with frying or chili.

« Fingnin mimè » or grilled cassava

The roots of cassava can be roasted with or without bark on embers or in wood fire. Grilled cassava is usually consumed alone by peasants as a snack.

The intermediate products

It is the transformation products that require further processing before being consumed. These products are numerous and include:

- L'amidon et le tapioca

There are two types of starch that differ in their characteristics and uses: sour or sweet starch. Soft starch is obtained after an extraction process which separates the starch from the other constituents while the sour starch is obtained by fermentation followed by extraction (Ene, 1992). Bitter starch, with a characteristic flavor, has several applications in biscuits and bakeries (Balagopalan, 2002; Dermiate *et al*., 1999) [14, 7]. Mild starch is used in the textile, paper and bakeries industries (Ene, 1992). Tapioca is dehydrated cassava starch and cooked at a moderate temperature. After extraction of the starch milk, it is decanted and the starch is collected. The latter is then crumbled using a "sassado" raffia sieve and then cooked over a low heat (Nago and Hounhouigan, 1998) [38]. It can be consumed in water or as a viscous slurry mixed with milk.

- Lafou

Lafou is a fermented manioc flour. Traditionally, it is prepared by soaking the roots in water for 3 to 4 days during which the flesh softens and undergoes fermentation (retting). The softened roots are manually crushed, the fibers are removed and the puree dried in the sun for 1 to 3 days and then ground into flour (Oyewole & Odunfa, 1990) [42].

- Cassettes, manioc flour and pasta

Cassava is also sought after for its ability to be processed into cassette which in turn is reduced to flour. The latter is used for the preparation of various meals intended for human consumption or for the manufacture of feedstuffs (Hongbété, 2004) [23]. Different traditional methods are used in the manufacture of cassettes. The easiest way is to dry the roots peeled, whole or cut into pieces. This method does not require much labor, water or fuel. The resulting cassettes are processed into flour by grinding. Cassava flour can also be produced after peeling, grating, pressing, sieving and drying followed by grinding (Houngbété, 2004).

Elaborated products

In Benin, these products are varied and the modes of transformation sometimes differ from one region to another.

- **Fufu**

The preparation of the fufu follows the same production process as the lafou except for drying. Thus, the product obtained after retting is transformed into balls which serve to prepare the dough called fufu (Mathew and Moorthy, 1998) [33]. This product is common in West Africa, particularly in Ghana (Balagopalon 2002, Lancaster *et al*., 1982) [30]

- **Gari**

Of all the main products obtained from cassava, gari is the best known and most widespread in West Africa (Eggleston *et al*., 1992) [16]. The roots are peeled, washed and shredded. The rasp is put into bags and left to ferment for at least 48 hours. The paste is then pressed, crumbled and then cooked to dryness (Ene, 1992). It is a gelled product with an acidulated taste, whitish to yellow in color (Nago, 1995). In Benin, we distinguish several types of gari which differ from one another according to the size and duration of cooking (Muchnick and Vinck, 1984) [35]:

- gari "sohui", which is roasted to near-total desiccation;
- gari "ahayoé", which is gari "sohui" with a finer grain size;
- gari "zogbla" which is less dry than the previous two. It is a product that has undergone half-baking before being dried in the sun;
- gari "go", which is the refusal stemming from the sifting of gari ahayoé. It consists of coarse grains.
- The transformation of cassava into gari is arduous, consuming time and energy. In fact, the production of gari requires a large labor force and a high quantity of firewood for roasting (Nago and Hounhouigan, 1998) [38].

- «Gbéli»

It is produced from pressed rasp seasoned with various condiments (chilli, onion, salt). The dough is then shaped into pellets which are fried a first time for a few minutes in peanut oil or coconut oil. These pellets are then removed, flattened and turned into rings which are fried again in the oil. This product is consumed alone or with grilled peanut or coconut almond as appetizers (Hongbété, 2004) [23].

- **«Galikponnon» or gari bread**

It is produced from pressed manioc rasp, arranged in thin slices (1 cm) and 15 to 20 cm in diameter, on a flat bottomed vessel of cooked clay, which is brought to the fire. The two faces of the washer are burned by contact with the wall of the container. The "galikponnon" is thus obtained, which is eaten with peanuts or coconut almonds. This product is mainly prepared in the Department of Mono (South-West of Benin), especially in lagoon zones (Nago, 1989) [39].

- **«Agbéli klaklou»**

It is prepared from pressed, seasoned and shaped into pellets which are fried in coconut oil or peanut oil. It is most often consumed with copra (Hongbété, 2004) [23]. Note that very little or no study is yet conducted on this product well consumed by the Beninese population.

- **«Ayan» or cassava puree**

Ayan is a manioc puree prepared from boiled cassava, defibrated and processed into paste after cooking in a mixture of water and seasoned palm oil. This puree is consumed with fry made with palm oil. It is particularly appreciated by the lagoon fishing communities of South Benin (Nago, 1989).

- **« Abloyoki »**

It is made in southern Benin from manioc rasp, fermented and cooked in dry heat. (Nago and Hounhouigan, 1998) [38].

- **« Chikwangue »**

It is the most popular product of cassava processing in Central Africa (Congo-Kinshasa, Congo-Brazzaville...). The roots of cassava are peeled, soaked in water for 3 to 5 days to undergo retting. The fibers are then removed and the pulp undergoes a retting process before being drained. The pulp is then ground and packed in plantain or other Zingiberaceae species and steamed (Mathew and Moorthy 1998, Balagopalon 2002, Lancaster *et al*., 1982) [30, 33].

- **« Attiéké »**

It is a popular fermented product in Côte d'Ivoire. The roots are peeled, washed and soaked in water for initial fermentation. Then they are ground and the dough is left to ferment for 2 days in jute bags and then pressed. Finally, the dough is rolled into granules which are steamed (Balagopalon, 2002, Lancaster *et al*., 1982) [30]. Other cassava valuation derivatives are produced in Benin but in urban or peri-urban areas. Among these products are snacks, cassava bread, cassava bread, biscuits, maltose syrup, etc. Figure 1 shows the traditional manufacturing process of certain derived products such as starch, tapioca, cossettes, attiéké, gari and raw meal. (IFAD, 2008) [24].

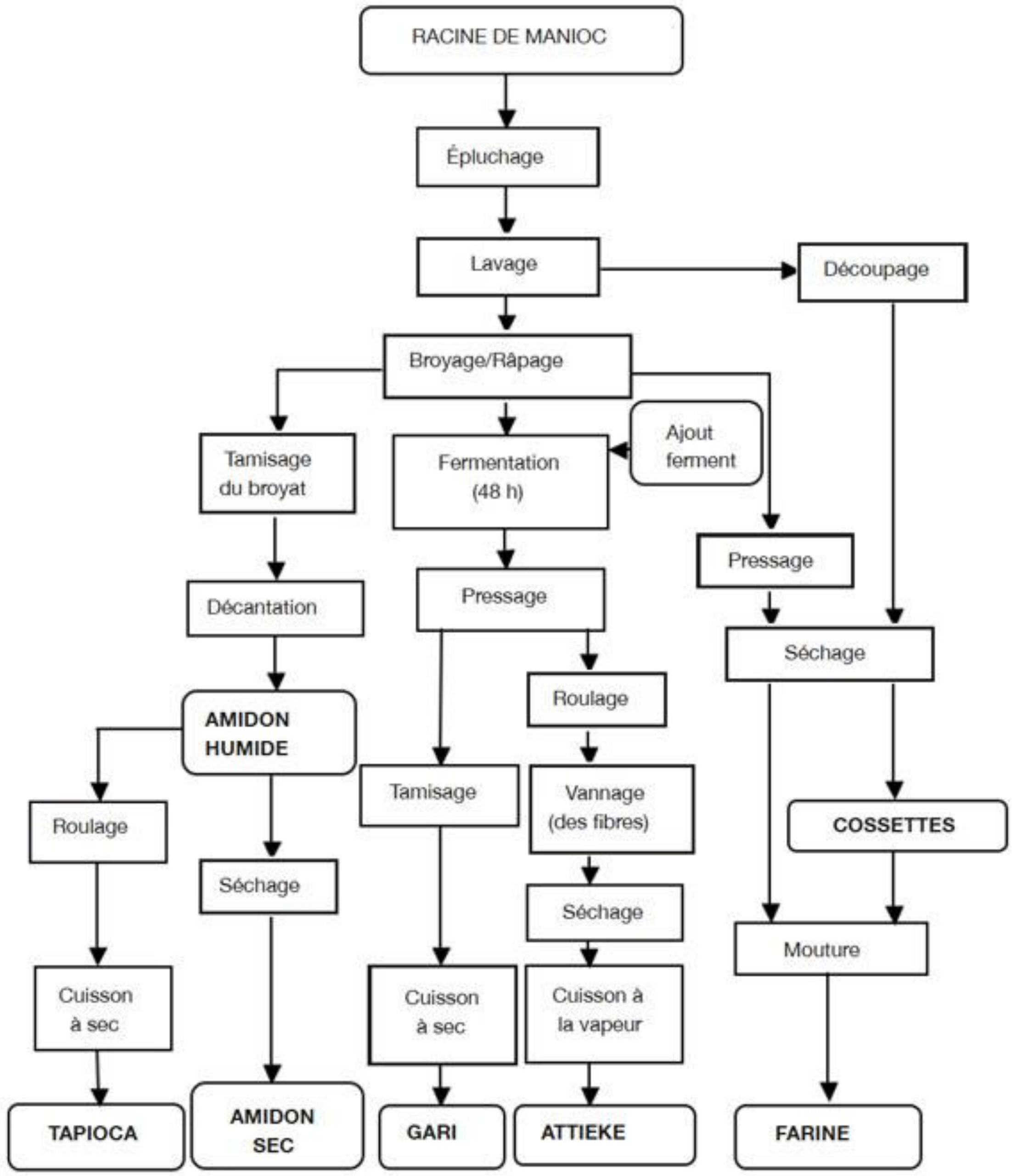

Fig 1: Technological diagram of production of certain products derived from cassava

Conclusion

From this synthesis, it emerges that cassava contributes significantly to meeting the basic nutritional needs of populations. Once considered to be the food of the poor in tropical countries, cassava has become a plant of great economic importance at the global level, both in the fight against hunger and food security and in the development of various agro- ... because of its nutritional composition, the diverse range of products derived from its processing and the benefits that can be derived from it by improving its food and nutritional quality, it is necessary to investigate products not yet produced explored for an efficient valuation of this root.

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