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Cassava cell wall disruption methods: A review

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ABSTRACT

Cyanogenic compounds such as linamarin, lotaustralin and linustatin are found in roots of cassava (Manihot Esculenta, Crantz). Those compounds are located in cell vacuoles while their hydrolytic enzyme, the linamarase is present in cell wall. Once the cell wall is disrupted, the cyanogenic compounds are hydrolyzed by the linamarase, producing glucose, acetone and hydrocyanic acid under favorable conditions. The main condition for cyanide production and elimination is the disruption of cassava cell wall, to promote the contact of cyanogenic glycosides and the linamarase. The cell wall disruption can be obtained by mechanical methods that are: shear grating, grating by pounding and grating by impacting. Cell wall disruption can also be done by solid-state fermentation or submerged fermentation that are chemical methods. It can finally be done by the combination of mechanical method for cassava division, followed by fermentation in hot water.

Keywords: Cassava, Fermentation, Grating, Impacting, Pounding.

1. INTRODUCTION

Cassava (Manihot esculenta, Crantz) is an important root crop, grown in the tropical regions from around the world [1]. Cassava plant is drought tolerant and resistant to diseases and pests[2]. These attributes make cassava a valuable food security crop and an insurance against famine. Cassava roots and leaves are consumed as staple food for more than a billion people living in the tropical regions of Africa, Latin America and Asia [3]; they are also used as animal feed and as raw material for industries[4]. Cassava leaves, stems, peel and pulps contain cyanogenic glucosides, linamarin (93 %), lotaustralin (4 %) and linustatin (3 %), in all their tissues [4]. Those cyanogenic glucosides liberate acetone cyanohydrin and hydrogen cyanide upon hydrolysis by the endogenous enzyme, linamarase [5]. The residue of cyanogenic glucosides, the acetone cyanohydrin and hydrogen cyanide are called cyanide, they make cassava foods toxic and dangerous for human and animal consumption. During drought years, total cyanide content of cassava roots increases. The World Health Organization (WHO) has set the safe level of cyanogens in cassava flour at 10 ppm[6]. The consumption of insufficiently processed cassava and its foods may cause cyanide poisoning with symptoms of vomiting, nausea, stomach pains, headache, weakness and death [5, 7]. Continuous cyanide intake can cause endemic goiter and cretinism in iodine deficient areas and is almost certainly the cause of konzo, an irreversible paralysis of the legs of sudden onset, which occurs particularly in children and women of child bearing age [3]. The detoxification of cassava roots is based on the production and the elimination of hydrogen cyanide. The production of hydrogen cyanide is itself based on the hydrolysis of cyanogenic glucosides by the linamarase whenever and wherever a cassava cell tissue is disrupted. In this review, our main objective is to examine methods, tools and equipment used for disrupting cassava cell tissues in order to produce cyanide.

2. DISCUSSION

2.1. Cyanide

Fresh cassava roots contain linamarin, lotaustralin and linustatin in each cell vacuole, and their hydrolyzing enzyme, the linamarase in the cell tissue [4, 8]. Those cyanogenic glucosides liberate acetone cyanohydrin and hydrogen cyanide upon hydrolysis by the endogenous enzyme, linamarase [5,8,9]. The meaning of the word cyanide includes the cyanogenic glucosides, the acetone cyanohydrin and the hydrogen cyanide [4, 5].

2.2. Production mechanism

The cyanide production mechanism is a three-step process [4]:

- The disruption of a cassava cell wall;
- Hydrolysis of the linamarine by linamarase in presence of water into glucose and acetone cyanohydrin;
- Decomposition of the acetone cyanohydrin into hydrogen cyanide and acetone at temperature greater than 37 °C or pH greater than 4.

According to Nambisan and Sundaresan [9], the quantities of water and linamarase initially present in a cassava root are enough for the hydrolysis of all the cyanogenic glucosides.

2.3. Production methods

2.3.1. Mechanical methods

Cassava cyanide production by mechanical methods consists of developing a pressure, that is an effort on a point, a line or a surface localized on the cassava root. The effect of that pressure is the division of cassava roots into small parts, the higher the number of divisions, the higher the number of cassava cell tissue disrupted.

2.3.1.1. Cutting

Cutting is the separation or the opening of a physical object into two or more portions through the application of an acutely directed force. However, any sufficiently sharp object is capable of cutting if it has a hardness sufficiently larger than the object being cut and if it is applied with sufficient force. Cutting is a compressive and shearing phenomenon, and occurs only when the total stress generated by the cutting implement exceeds the ultimate strength of the material of the object being cut. The applicable equation for cutting is:

$$\tau(\text{pas}) = \frac{F(N)}{A(m^2)} \quad (1)$$

Were;

$\tau(\text{pas})$: the stress generated by a cutting implement, expressed in pascal;

F(N): the applied force in Newton;

$A(m^2)$: area of the contact zone between the cutting implement and the object being cut, expressed in square meter.

2.3.1.2. Cassava grating

Grating cassava roots consists of subdividing the whole root into smaller units suitable for further processing[3,10,11,12,13]. Grating enhances the contact between the enzyme and cyanogenic glucosides, resulting in higher hydrolysis [14,15]. Furthermore, grating enhances drying which is necessary for the production of cassava flour. The grating provides larger surfaces which speeds up the drying process as it is crucial to prevent spoilage and microbial growth. A wide variety of size reduction equipment is available, and they can be classified based on their primary mechanical action. For grating, the two most common mechanical actions are impact and shear force [16,17].

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2.3.1.2.1. Shear force grating

A shear force is a force acting in a direction parallel to a surface or to a planar cross section of a body [16]. Shear forces are unaligned, but parallel forces acting on a surface or on an object [12,16]. Being unaligned means that one force is going in one direction and another one is going in another direction. Cassava graters using shear forces are provided with revolving abrasive cylinder, discs, or blades.

2.3.1.2.1.1. Manual grating

Manual grating, also called hand held grating, use metal device with holes surrounded by sharp edges used to cut food into small pieces [16]. This method is commonly used to grate vegetables, cheese and lemon or orange peel, spices such as ginger and nutmeg and can also be used to grate soft foods. It is used at household level for grating up to 50 kg of fresh cassava roots. Manual graters are usually made from perforated metal sheets with the grating zone having a sharply extruding face.

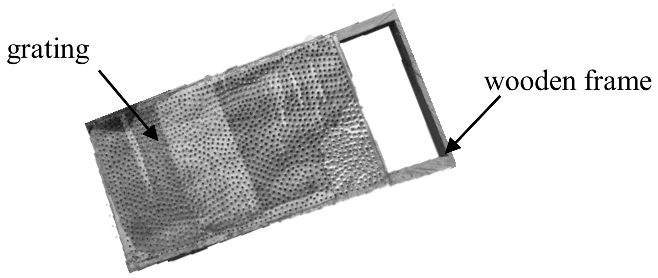

Figure 1: Hand grater

Figure 1 presents a four-side manual grater. The size and the sharpness of the extruding zone affects the efficiency of the grating operation in terms of tissue disruption [16,18]. The smaller the grating area, the higher the number of cassava cell wall cut, favouring the hydrolysis of cyanogenic glucosides by the linamarase. The use of manual graters is labour intensive and expose the operator’s hand to injuries when processing smaller roots.

2.3.1.2.1.2. Hand rotary grating

Hand rotary grating use a handheld grater that generally consists of four parts: a box, a turning mechanism with a grating surface that is formed into a circular drum, a crank and the support [17,19]. Figure 2 presents a hand rotary grater.

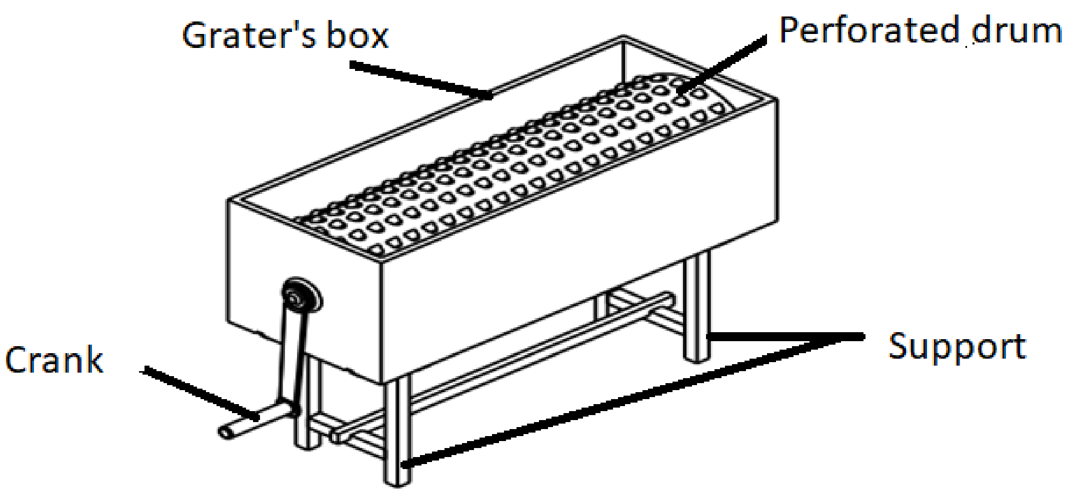

Figure 2: Hand rotary grater [17].

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The box contains the drum and the cassava roots being grated. During grating, the grater is supported against the operator´s leg in a downward slant direction and the rubbing action of the cassava root against the grating surface is in the same direction. Cassava particles size can be fine enough and the productivity can range from 20 to 50 kg fresh cassava roots per hour, depending on the operator. It is not possible to completely grate a whole cassava piece, 5 to 10 % of the cassava root has to be left ungrated [16,19, 20].

2.3.1.2.1.3. Pedal operated grating.

This method of grating uses a grater that is operated thanks to a pedal which can be hand operated or with the legs. Jekayinfa and collaborators [21] developed and evaluated a pedal operated cassava grating machine, presented in figure 3, which mainly consisted of a hopper, grating plate and a power generation and transmission unit. The power needed is generated manually through the pedals and transferred by means of a chain attached to the sprocket of a free wheel. Two operators are needed to use this type of a grater, one person to pedal and the second person to feed in the tubers into the hopper. After evaluating the performance, the pedal operated cassava grater had a capacity ranged between 28.30 kg/h and 45.00 kg/h, which was concluded to be 220 % above capacity of a manual grater.

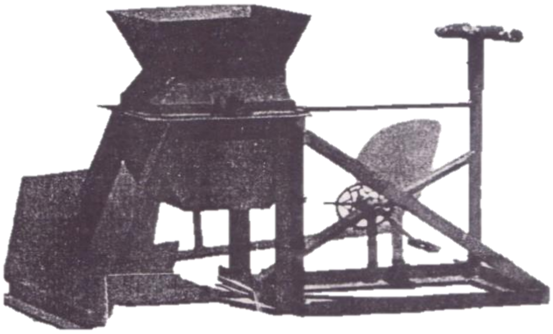

Figure 3: Pedal operated cassava grater [21].

Yusuf et al [22], designed and fabricated a simple pedal operated cassava grater suitable for rural dwellers. This grater, working on same principle as that presented by Jekayinfa and collaborators [21], was fabricated using locally available materials mainly hardwood for constructing the frame, hopper, grating roller and the outlet. Iron rod for the shaft, three roller bearings, driver and driven pulleys, belt, bicycle pedal for manoeuvring and galvanized sheet for the grating surface on the grating roller. The grating capacity of the cassava grater was found to be 102.9 kg/h, and the grater had a grating efficiency of 90.91 %.

2.3.1.2.1.4. Motor-powered grating

Motor-powered grating is necessary for processing large scale of fresh cassava per day. Motor-powered graters productivity ranges between 0.5 to 4 tonnes per hour [19, 23]. Figure 4 presents an electric cassava grater. Powered equipment generally consists of a hopper, an unloader, a driving force, a grater cylinder, a transmission system and a machine frame [17, 24].

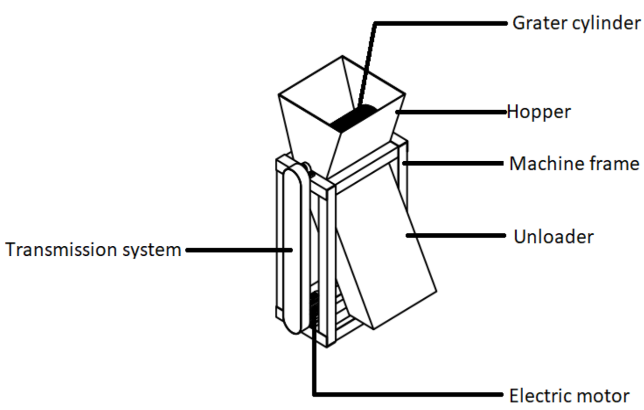

Figure 4 Motor-powered grater (adapted from Parmar and Precoppe, [17])

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Fresh cassava roots are introduced in the hopper that serves as a container. The hopper is located on top or on the side of the grater cylinder, so that the material entering the hopper will be forwarded to the grater cylinder due to the influence of the gravity [18,19,23]. Cassava grates move through the unloader and to fall into a storage container. This component also serves to prevent the grated from spreading from the grated cylinder. The driving force can be an electric motor or a combustion engine. The machine frame holds the grater cylinder, the driving motor, and other supporting components. It is a basic component and the main seat of the machine. It must be strong enough to withstand heavy loads and vibrations from the machine when it is operated. The transmission system grater consists of four components, including a shaft, two pulleys, a belt and bearings. The shaft is used to transmit rotation from the electric motor shaft to the cutting blade shaft. The driving pulley is mounted on the motor shaft, the other one is mounted on the grater cylinder shaft. The diameter of the different pulleys can increase or decrease the engine rotation speed. The belt serves to channel the rotation of the pulley on the electric motor to the pulley on the cylindrical shaft of the grate. Two bearings are used to guide the grater cylinder shaft in rotation.

2.3.1.2.2. Grating by pounding

Grating by pounding in food industry is the process of dividing grains, roots, tubers and other food crop, into small size objects, by repeatedly hitting or compressing them against a harder surface [25]. Pestle and mortar are certainly the most spread devices for grating by pounding food materials in towns and in remote rural areas from around the world [13,16]. Figure 5 presents a pestle and mortar.

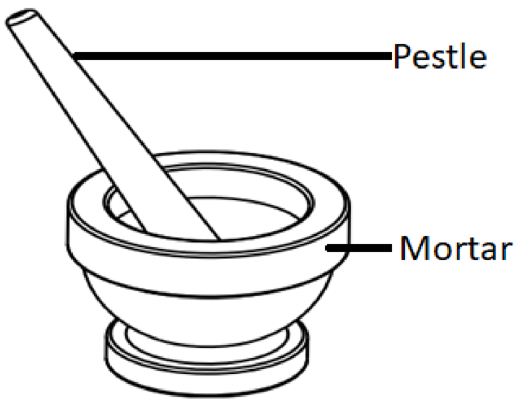

Figure 5: pestle and mortar (adapted from Parmar and Precoppe, [17])

The mortar is a durable bowl, commonly made of stone, wood or ceramic. The pestle is a rounded grinding club often made of the same material as the mortar. They are used to mix, grind, smash, and pound both dry and wet products in general, cassava fresh roots in particular. Mortar and pestle are used for milling up to 50 kg of dried cassava by pounding for flour production [13]. Mortar and pestle are used for pounding up to 15 kg of wet and fermented cassava for the “baton de manioc” production [26]. Finally, they are used for pounding up to 15 kg of fresh cassava for the production of many other traditional foods in Cameroon, in Nigeria and the Central African Republic. Grating by pounding cassava is tiring and exposes the product to dust.

2.3.1.2.2.1. Grating by impacting

Grating by impacting in food industry is the process of dividing cereals, grains, roots tubers and other food crop by clashing or colliding them with a highly rotating solid object [13,16,23]. Due to its definition, grating by impacting is only done by motor-powered equipment like hammer mill graters. A hammer mill grater is a machine that uses rapid hammer blows to break aggregate material into small pieces. Figure 6 presents a hammer mill. It consists of a hopper, a drum, a shaft, a frame, a motor and an unloader.

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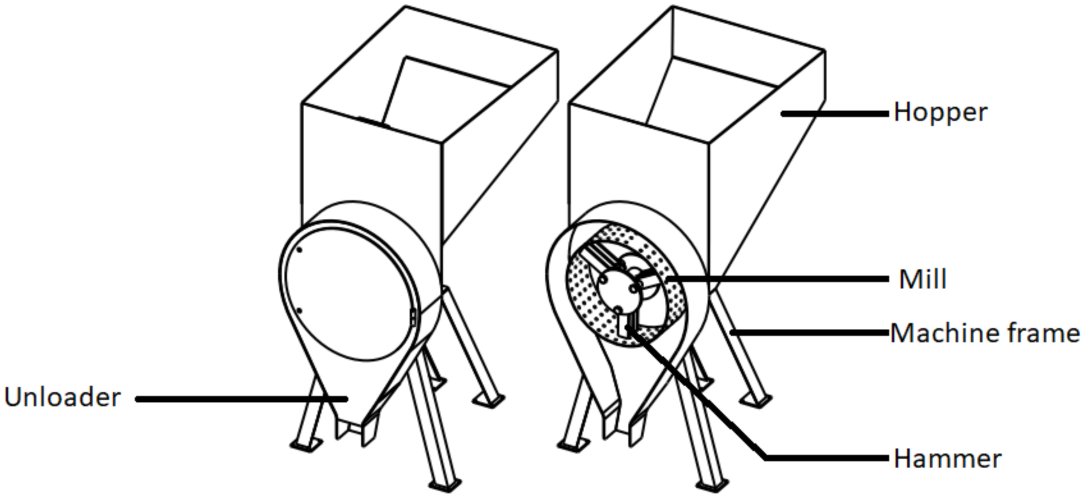

Figure 6: Hammer-mill grater (adapted from Parmar and Precoppe, [17])

As the hopper, the drum, the frame, the motor and the unloader have similar functions as in the case of cassava graters using shear forces, description will only focus here on the shaft. Located inside the drum, the shaft can be horizontal or vertical, depending on the position of the electric motor or the combustion engine. At the end of the shaft, are attached two, three of four stainless steel bars called hammers. As the shaft rotates at high speed, fresh or dried cassava are reduced by the impact of the hammers and leaves the drum when it is small enough to pass through the screen mesh at the bottom. The use of hammer mill graters disrupts effectively cassava cell walls and ensures the hydrolysis of the cyanogenic glucosides by their enzyme, the linamarase, promoting the detoxification of cassava. They can be used for grating up to 4 tonnes of cassava per hour, depending on the power of the motor. Unfortunately, hammer mill graters have many drawbacks: they are very noisy, very dusty and very intrusive [27].

2.3.2.Chemical method: cassava fermentation

Fermentation is the breakdown of a substance by bacteria, yeast, or other microorganisms, typically involving effervescence and the giving of heat [13, 28, 29, 30]. The cassava fermentation process consists to use microorganisms to disrupt cell wall in order to promote the hydrolysis of cyanogenic glucosides by the linamarase.

2.3.2.1. Cassava fermentation practices

Many common practices are used in cassava fermentation:

2.3.2.1.1. Natural fermentation

This method relies on naturally occurring microorganisms present in the environment and on the surface of cassava roots. The peeled and grated cassava is left to ferment in open vessels or wrapped in leaves in order to allow airborne bacteria and those that are naturally present on the cassava to commence fermentation [28].

2.3.2.1.2. Starter culture fermentation

In order to initiate fermentation, particular starter cultures containing well-known strains of advantageous microorganisms are added to the cassava mash. These cultures can be bought or extracted from fermentation batches that have already been successful. Common starter cultures include lactobacillus species for lactic acid fermentation and specific yeast strains for alcoholic fermentation[31].

2.3.2.1.3. Controlled fermentation

The microbial activity and the fermentation process can be affected by adjusting environmental parameters like as temperature, pH, and moisture content during the fermentation process. Fermentation kinetics can be controlled and desired product qualities can be produced by maintaining ideal conditions.

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2.3.2.1.4. Inoculum Transfer

In order to start fermentation in a new batch of cassava, a little amount of a batch that has already fermented well known as a starter culture is transferred. Consistent fermentation is promoted by ensuring that the desired microbial strains from a previously fermented batch are introduced into a new one.

2.3.2.2. Cassava fermentation techniques

Two fermentation techniques are commonly used in practice: solid state fermentation and submerged fermentation.

2.3.2.2.1. Solid-state fermentation

Solid-state fermentation is a promising technology for producing value-added products from cassava. In this process, microorganisms are grown on cassava biomass without the presence of free-flowing water. In that process, fresh cassava roots are peeled and crashed. Yeast and nutrient solution are added to cassava pulp and let to ferment for days. The fermented cassava is then pressed, dried and milled to produce flour or it is pressed, sieved and fried to produce gari. In that process, cassava cell walls are widely disrupted by crashing followed by the action of microorganisms [32, 33].

2.3.2.2.2. Submerged fermentation

Submerged fermentation involves the soaking of whole peeled or unpeeled cassava roots in water for various periods, considering the end product desired. The mechanism of tissue disruption is based on the fact that water molecules attract each other due to polarity. Figure 7 presents five water molecules bound by hydrogen links.

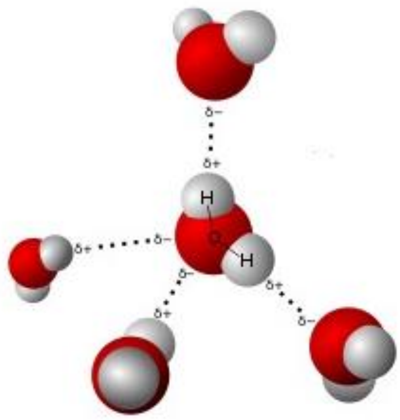

Figure 7: Water molecules

Although the net charge of a water molecule is zero, water is polar because of its shape. The hydrogen ends of the molecule are positive and the oxygen end is negative. This cause water molecules to attract each other and other polar molecules. As water molecules are attracted and bound to each other in a cassava root, containing them requires more space [28, 33, 34]. Due to molecular forces, cassava tissues are disrupted and the cassava root increases in volume. Cassava tissue disruption permits the hydrolysis of cyanogenic compounds by the linamarase, promoting cassava detoxification.

Submerged fermentation can also be done using hot water. Heating a liquid increases the speed of the molecules. As temperature increases, the kinetic energy of the molecules in the water increases. The movement of the molecules gradually overcome forces of attraction between the molecules, with the result that they have greater freedom to move over grater volumes. In this case, cassava tissue disruption is due to molecular agitation.

2.3.3.Combined methods

Mechanical, chemical and thermal approaches can be combined for a more effective detoxification of cassava [33, 35]. Fresh cassava roots can be grated, pound or crushed to reduce them into small particles. Those particles can

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be fermented by submerged fermentation to benefit from the degrading actions of microorganisms and the water molecular attraction in hot water to benefit from the kinetic energy of water molecules. As a result of that cumulative approach, cassava can be detoxified in a very short time.

3. CONCLUSION

Understanding how can cassava cell walls can be disrupted is key for cassava roots effective detoxification. That disruption permits the hydrolysis of the cyanogenic compounds: linamarin, lotaustralin and linustatin to be hydrolysed by the linamarase in presence of water. Manual grating, manual pounding and fermentation of cassava roots can be done successfully at household level even in remote rural areas. Hammer mill grating is the only process requiring motor and power, making it suitable for medium scale and industrial application.

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