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Cassava traits and end-user preference: relating traits to consumer liking, sensory perception, and genetics

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ABSTRACT

Breeding efforts have focused on improving agronomic traits of the cassava plant however little research has been done to enhance the crop palatability. This review investigates the links between cassava traits and end-user preference in relation with sensory characteristics. The main trait is starch and its composition related to the textural properties of the food. Pectin degradation during cooking resulted in increased mealiness. Nutritional components such as carotenoids made the cassava yellow but also altered sweetness and softness; however yellow cassava was more appreciated by consumers than traditional (white) varieties. Components formed during processing such as organic acids gave fermented cassava products an acidic taste that was appreciated but the fermented smell was not always liked. Anti-nutritional compounds such as cyanogenic glucosides were mostly related to bitter taste. Post-harvest Physiological Deterioration (PPD) affected the overall sensory characteristics and acceptability. Genes responsible for some of these traits were also investigated. Diversity in cassava food products can provide a challenge to identifying acceptance criteria. Socio-economic factors such as gender may also be critical. This review leads to questions in relation to the adaptation of cassava breeding to meet consumer needs and preference in order to maximise income, health and food security.

KEY-WORDS

Manihot Esculenta Crantz, consumer acceptance, sensory properties, quality traits, genetics, market

INTRODUCTION

Plant breeders are working on improving the traits of the cassava crop because it has the potential to tackle malnutrition and generate income in parts of the world where people are food insecure and have little resources.

Over the years, breeders have developed new and improved varieties of cassava that have been distributed to and promoted among local farmers in sub-Saharan and South American countries (Acheampong, 2015). These varieties have improved characteristics or traits such as pest resistance, drought resistance, improved yield, improved micronutrient content (*i.e.* biofortified crops) etc. Breeders have mostly focused on improving agronomic traits of varieties that could be adopted by farmers (*i.e.* using participatory breeding with farmers). The main varietal characteristics important for farmers are crop yield and disease resistance - for example, new African Cassava Mosaic Disease resistant varieties may have potentially benefited Africa to the sum of $1.2 to $2.3 billion per annum (Thresh et al., 1997). However the end-users (*i.e.* processors; consumers) and their preferences have often not been taken into consideration (Figure 1). Published works on the level of adoption of new varieties with reference to end-users are few and none of these have appeared to indicate the impact in economic terms with respect to investment. Akoroda and Ikpi (1992) reported that the annual level of adoption of new cassava varieties in southwestern Nigeria was statistically around 34% and that was above the national average. Acheampong (2015) published that between 1993 and 2015 the National Agricultural Research System, Ghana, officially released 18 improved cassava varieties which were high yielding, disease and pest resistant and early maturing. However, adoption of these varieties by mainly smallholder farmers was very low. Higher yield, a major focus of recent breeding research, had no effect on farmers' adoption decisions. Farmers would not see the need to adopt more productive cassava varieties when constraints to marketing were not alleviated within the value chain. While focus on high yield and disease resistance by national agricultural research systems remains imperative, adoption could be improved with greater understanding of farmers' cassava preferences for certain cassava attributes. Bennett et al., 2012 reported that while existing cassava breeding programmes based on farmer led trait identification can have some successes, combining the breeding work with market needs will lead to higher success. Bennett et al., 2012 recommended that a 'new alliance between demand and supply-side ends of cassava value chains should be built in order to promote a more market-driven client-oriented research'. The impact of other enabling factors such as climate change and the role of gender in the value chain on market demand was also very important.

There are also few publications regarding the production and economic importance of cassava products in Africa. While the FAO give overall production of cassava (which increased by 30% in Africa between 1996 and 2013), this is not broken down into the product groups. It is the authors estimate that the most important of cassava product consumed is fresh boiled cassava, followed by gari (70% of production of Nigeria), fufu and lafun. However, these are estimates and would need to be verified.

Farmers in Africa grow several cassava varieties and researchers identified over 1000 local cassava varieties in six counties (Congo, Côte d'lvoire, Ghana, Nigeria, Tanzania and Uganda) (Nweke et al., 2002). While it is not known how many new varieties have been released, the result is that some of the new varieties that breeders spent many years and money developing may not been adopted by local people because they do not meet market needs that are driven by end-user preference.

There is a paucity of information in the literature that explores the relationships between cassava traits and end-user preference, especially in Africa. The review will highlight how much research has been published in this area and will seek to identify gaps in knowledge and make recommendations to help orientate future research programs that wish to take into account end-user (*i.e.* processor and consumer) preference whilst breeding for new or improved varieties of cassava. The paper focuses on Africa although some examples may be taken from other parts of the world and other related crops when this contributed to the discussion.

BACKGROUND

Cassava importance in the world and for food security in Africa

Cassava (*Manihot Esculenta Crantz*) is the fifth most important staple in the world, and also the second most important staple in the least developed countries after rice both in terms of production and food quantities consumed (FAOSTAT 2013). In the developing world, over half a billion people depend on cassava essentially for food of which 300 million are in Africa. In Africa where cassava is used mostly for human diet and it is therefore a crucial crop for food security.

The use of cassava in industry for non-food purposes is present in Africa but to a limited extent compared to Asia and Latin America (Naziri et al., 2014).

Tracing back to its history, cassava originated from South America and then was exported to other parts of the world with tropical climate such as Africa some centuries ago. Cassava has been fully integrated to the African cuisine and culture and is used in the preparation of numerous local dishes. The starchy root is the main product of cassava but the leaves can also be used for animal and human consumption (Ufuan Achidi et al. 2005). The crop is versatile and can be prepared into a variety of foods, but also be used as feed for animals and industrial products such as starch.

In the recent years cassava has taken importance because it is drought tolerant and grows easily with little labour and in poor soils. Cassava is an easy and cheap source of carbohydrate (starch) and therefore of energy it produces often more energy per hectare than any other crop. With the global warming and increase in world population, cassava's role in food security will probably come to rise in the years to come.

Though cassava crop has many qualities, it also presents a number of shortcomings. One weakness is that its nutritional value is mostly composed of starch; cassava contains very few proteins and other micronutrients of importance for a balanced diet. As a result, high consumption of cassava can lead to hidden hunger which is a deficiency of nutrients such as vitamins and minerals. In addition, some varieties of cassava contain cyanogenic glucosides that are harmful for health and therefore require careful processing in order to remove these

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compounds to safe levels (Ferraro et al., 2015). Finally another major constraint is the short shelf life of cassava roots of 2-3 days after harvest means that it must be quickly consumed or processed (Blagbrough et al., 2010; Sánchez et al., 2010).

These constraints have led international research initiatives such as the CGIAR’s Root, Tubers and Bananas Program to take a close look at cassava in order to find strategies to overcome these hurdles. These include different approaches; for instance the BioCassavaPlus Programme is looking at improving the nutritional content by developing nutritionally enhanced varieties (higher and better protein content; micronutrients such as iron, zinc and carotenoids) with improved characteristics (low cyanogenic potential; pest and disease resistant and PPD (post-harvest physiological deterioration)) using transgenic strategies (Sayre et al., 2011). Nutrition can be improved by the use conventional breeding techniques to increase levels of the same micronutrients of interest in the cassava roots (*i.e.* HarvestPlus) (Bouis et al., 2013). Other initiatives include improving the efficiency and productivity of cassava value chains (*e.g.* the Bill and Melinda Gates- Cassava: Adding Value for Africa (C:AVA)project, the European Commission Food Security Thematic Programme- Cassava Growth Markets (Cassava GMarkets) project) or to reduce waste and turn them into increased value (*e.g.* the European Commission Framework 7 funded project, Gains from Losses of Root and Tuber Crops (Gratitude) project).

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Cassava breeding

The first step in developing improved varieties of cassava is the breeding process. Breeders from CGIAR and National Agricultural Research centres have taken interest in cassava realising its potential as a subsistence crop to help tackling food security issues in developing countries.

Cassava is highly heterozygotic, which makes challenging to predict the phenotype of the crop. In addition most multiplication practice is vegetative using the stem of the plant to produce new plants of cassava (Sayre et al., 2010). Crossing (sexual reproduction of the plant) that will produce plants with combined characteristics of the parents is tricky because of the different plants having various flowering times (Ceballos et al., 2004). Scientific breeding of cassava only began recently compared to other crops -- a few decades ago - and therefore there are not as many genetic differences between wild and improved germplasms compared to other crops that have longer breeding history. Also the vegetative multiplication rate of cassava is slow: only about 5-10 cuttings can be obtained from one plant (Ceballos et al. 2004).

In spite of these constraints, great progress has been made over the last 30-40 years. Major traits such as improved yield, low cyanogenic content, improved resistance/tolerance to major diseases and pests, and high dry matter have been bred into the cassava genome and improved varieties released to farmers (Ceballos et al. 2004). A molecular map (Fregene et al., 1997) was first developed and published in 1997. The map has been utilised in quantitative trait loci (QTL) mapping studies in cassava for various traits, including resistance to pests and diseases, yield, morphological and quality traits. It is now clear that this gene map has helped accelerating the

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development of improved varieties (Sayre et al., 2010). Recently a high dense genetic map of cassava that includes physical localisation of immunity related genes has been developed and adds to the knowledge of the cassava genome for agronomical important traits.

An aspect that has been mostly ignored by breeders however in their effort to improve cassava crop is the consideration of end-user (including processer and consumer) acceptance. Sensory characteristics (*i.e.* palatability) are linked to end-user acceptance and are important to ensure that the improved crop will be adopted and consumed by the local population it was purposed for. Breeding goals and activities should encompass a consideration for crop adoption and end-user acceptance (Acheampong, 2015). Breeders, however, need access to knowledge to understand how improved cassava varieties might be perceived by end-users and how modifying cassava quality trait might affect processing ability, sensory characteristics and consequently consumer acceptance and market demand.

Diversity in cassava products

Throughout Africa there are numerous cassava food products that have different sensory characteristics and acceptance criteria and this complexity can provide a challenge to identifying relationships with quality traits.

Acceptability of cassava products is therefore also closely dependent on the type of product and use that is proposed and these different uses of cassava shall be taken into account by the breeder. The type of products might have different quality criteria for the consumers and processors and acceptability would be also influenced by the ‘cultural’ sensitivities meaning that different parts of the world have different likings for different products. This review is restricted to cassava products that are consumed as opposed to those that have non-food uses.

Cassava products are produced through several steps of processing and many of these are common. Cassava roots undergoes peeling, followed by size reduction and boiling or soaking in the first step. This is usually followed by fermenting and pressing or cooking or drying. A large variety of products are prepared using a combination of different processes. The need for cassava roots to be processed is also linked to the presence of cyanogenic glucosides that require in some bitter high-cyanide varieties numerous steps of processing in order to detoxify the product.

In addition, within the same product categories, there are differences in the process (fermentation duration, cooking temperature, extent of drying, etc.), which will lead to variants in the final product in order to meet local preferences and traditions. Variations in the process will have an impact on the sensory quality of the product and hence on consumer acceptability.

End-user acceptance

End-users are consumers of the cassava products and processors could also be included as end-users. End-user acceptance is mainly influenced by the sensory perception of the product.

Sensory perception

Sensory perception of the product will relate to the appearance, odour, texture and taste of the cassava product. Sensory characteristics of a product are attributes that describe a product in

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terms of appearance (*e.g.* colour: white or off-white), odour (*e.g.* fermented or not), texture (*e.g.* soft or hard), and taste (*e.g.* sweet or not sweet). The product should be characterised in terms of sensory attributes that will be then related to end-user acceptance.

Breeding to improve cassava traits may also influence sensory characteristics of the cassava products. End-users are susceptible to perceive that the cassava product presented to them has different characteristics to the one they are used to consume. Some of the changes in cassava traits may be perceived in a positive or negative way by end-users and therefore affect acceptance.

Processor acceptance

Processor acceptance is linked to the quality of the roots, their ability to be processed and also to the yield of the processed product from roots. Processors are looking to maximise yields of products for business purposes. Processor acceptance is related to some physiological properties of the raw material (e.g. postharvest physiological deterioration, storage ability, limited postharvest deterioration, absence of disease, pests), to some processing properties of the roots (e.g. easiness of peeling, grating, fermentation, cooking), and to physicochemical properties (*i.e.* dry matter content, starch content, low cyanide content etc.).

End-user preference

End-user consumer acceptance or preference is related to the sensory perception, and other factors such as the cooking quality, root size, appearance, odour, texture and taste, of the cassava products.

In addition the perception of a safe product (containing low cyanide), price or willingness to pay are important for consumer acceptability.

The consumer can react three different ways when tasting a product:

- The consumer likes the product. This leads to potential acceptance of the product but will be influenced by availability of the product, interaction with competing products and marketing and promotion within the market space.
- The consumer dislikes the product. This leads to potential rejection of the product but will be influenced by price, availability of alternatives and marketing and promotion.

The consumer neither likes nor dislikes the product. This will mean a neutral attitude but this implies a lack of incentive to buy the product unless other benefits are associated.•

To measure consumer acceptance or liking, standard hedonic scales have been developed to effectively give a measurement of consumer acceptance. The most common is the 9-point standard hedonic scale ranging from 1 = extremely dislike and 9 = extremely like (Meilgaard et al., 2007). A minimum of 50-60 consumers are required for the statistical analysis to be valid. Results from literature papers that interviewed less than this number of consumers however,

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illustrate weaknesses in the application of the methodology and the results of such studies have to be taken with precaution (Bechoff et al., 2015a).

Recent sensory techniques such as Penalty analysis (Varela and Ares 2014) are useful to determine the drivers for food acceptance, that are characteristics or attributes of the product that will drive the acceptance either positively (acceptance of the product will increase if it has this particular characteristic or trait) or negatively (acceptance of the product will increase if it has this particular characteristic or trait).

A more global picture of consumer and end-user acceptance should also encompass consideration for market demand and other factors that may influence user uptake and crop/product adoption: *i.e.* price, competing products, availability, constancy of supply and access to markets, domestic, regional and international trade. Market demand will drive uptake of new products (i.e. new breeding products). Potential substitutes and competing products to cassava should be examined.

Figure 2 summarises the typical relationships between cassava traits and end-user acceptance. Genetics and environment have been demonstrated to influence the physicochemical composition of the root in the ground and therefore on the cassava traits. After harvest, cassava roots will be stored and processed. Conditions of storage and processing (type of product; equipment etc.) will also affect the final characteristics and composition of the processed cassava. Processors evaluate the quality and acceptability of the roots under its raw form whilst consumers evaluate the quality of the processed product. Consumers who buy

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roots (i.e. in the market) will evaluate the quality of both raw (at the buying and processing stages) and processed cassava (at the consuming stage). It will be market demand, however, that will determine which attributes and traits are successful. Other external factors such as climate change, scarcity of the crop, season *etc.* will influence the demand and therefore the preference for fresh crop or processed product (Bennett et al., 2012; Acheampong, 2015).

WHAT ARE THE EXISTING ACCEPTANCE CRITERIA IN RELATION WITH SENSORY PROPERTIES FOR DIFFERENT CASSAVA PRODUCTS

In order to understand which quality traits are better accepted by the end-users it is important to consider the different types of products from cassava because of their diverse sensory and physicochemical properties.

Figure 3 categorises the products according to four types of processes. These have been divided into two main categories:

1) non-fermented products prepared using a single step process after peeling (boiling or frying) that applies mainly to low cyanide sweet cassava varieties; and the intermediate cassava products such as dried cassava chunks, flour and starch; and

2) fermented products that are made by several steps of processing because they are made mostly using the higher cyanide bitter type varieties that requires cyanide detoxification or because they meet local preferences. Roots undergo either fermentation under water -

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fermentation (submerged fermentation or soaking) or on the grated mash (solid-state fermentation).

The scope of the review will be limited to products from roots rather than from leaves. It should however be noted that cassava leaves play an important role in cassava acceptance and some varieties are adopted based on the quality of the leaves eaten as a vegetable, in particular in Central Africa (Congo, DRC, Centre Afrique, Gabon) (Ufuan Achidi et al. 2005).

Moreover the review will concentrate on products made from 100% cassava roots and not from mixtures because of the interference between cassava and other ingredients that will make difficult to relate acceptability to cassava traits.

Acceptability criteria for the groups are summarised in Table 1 and discussed below.

Non-fermented products made in a single step process

Non-fermented products are made from sweet varieties of cassava (that may contain low levels of cyanogenic compounds). Processes involve only a single step after peeling because it is sufficient to reduce the cyanide level to a safe level for human consumption. These products comprise boiled and fried cassava.

Boiled cassava

Texture *i.e.* softness is a very important criterion for the sensory quality of boiled cassava. Varieties that do not cook very well can still be hard after a prolonged period of cooking therefore affecting the acceptability of the product. Favaro et al., 2008 and Hongbété et al., 2011 also stressed that friability or mealiness was universally cited by consumers as the most important quality attribute of boiled cassava.

Fried cassava

Peeled cassava roots can be fried either as large chunks or as medium-size or as smaller-size slices such as fried chips. Grizotto and De Menezes, 2002 showed that crispness and friability were quality criteria for fried cassava. In addition Vitrac et al., 2001 reported that crisp quality was depending on oil content, colour and texture for the same dehydration level.

Non-fermented products made into industrial products: dried raw cassava products

Non-fermented products comprise dried chips, pellets, starch and high quality cassava flour (Table 1). These are often intermediate or industrial products that are used in the making of more elaborated food products from cassava. These products are in most cases non-fermented because the quality can be better controlled on non-fermented products rather than on spontaneously fermented products. Although users perception for these intermediate products is important these products firstly have to comply with quality standards because of their nature as industrial products.

Dried chips

Chopping and drying cassava is a current practice in Asia for animal feed and industrial uses and the use of dried chips and pellets for export are widely becoming increasingly popular in Africa. Drying cassava is also a convenient way of storing cassava that will be made into flour. Chips or

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pellet shape and uniformity as well as moisture content are important criteria for acceptability of dried cassava (Falade and Akingbala, 2010).

Cassava starch

Edible cassava starch (ARS:846 2012) is a neutral (odourless; bland in taste; not sour) product with a small particle size and a minimum of 95% cassava starch.

Cassava flour

Standard criteria for High Quality Cassava Flour (HQCF) are given (ARS 840 (2012). Shittu et al., 2007 found that the physicochemical properties of different HQCF from CMV resistant varieties greatly differ (starch content; viscosity etc.) and therefore the applications for the flour could be various. Variability in functional properties of the HQCF therefore opens opportunities for uses of HQCF in diverse industrial, food and non-food applications.

Overall major acceptability criteria for non-fermented products are that the final product should be not bitter and also sweet. Varieties with high dry matter content are generally preferred because of the texture, which is firmer and less moist.

Products fermented by (water) submersion

Common examples of products fermented by water submersion include fufu, lafun and chikwangue (Table 1). Fermentation has been ancestrally used as a means of preservation for products. Fermentation of cassava is a way to develop specific and appreciated product flavours and a grating step can help detoxify the product from cyanogens. Fermentation by submersion or also called water retting is a common process in humid areas where drying of products may be an issue.

Fufu

Fufu in Nigeria is a fermented dough made from cassava that is steeped as whole or sliced peeled roots in water and allowed to ferment for three days maximum. The fermented roots are then sieved and cooked to produce a homogeneous looking paste. In Central Africa (*i.e.* Cameroon, Gabon) and some parts of Nigeria the paste is dried into a flour that can be stored longer than fresh fufu. Fufu is ranked second in importance after gari in Nigeria (IITA, Cassava Biz 2005).

Fufu of good quality had homogeneous colour, was smooth, slightly sticky and stretchy (Opare-Obisaw et al., 2004; Falade and Akingbala, 2010). Although Opare-Obisaw et al., 2004 described the ideal taste of fufu as bland, other authors showed that the distinct fufu flavour and sourness were appreciated by consumers (Oyewole and Ogundele, 2004; Falade and Akingbala, 2010; Tomlins et al., 2007). The strong smell of fufu generated through fermentation however is not always liked by fufu consumers. The National Root Crop Institute (NRCRI) based in Umudike, Nigeria developed a process to make odourless fufu (Omodamiro et al., 2012) in order to respond to those consumers who do not like the strong smell of fufu.

Tomlins et al., 2007 noted a difference in acceptance rating in fufu products related to purchasing behaviour of males and females. When testing of acceptance of fufu among 300 consumers in urban centres in Nigeria, men (artisans and professionals) were more likely to want to purchase fufu in the wet form while women (younger in age, teachers and students) were more interested to purchase as flour. This difference, however, may be due to lifestyle differences because this was confounded with gender.

Tastes of different types of consumers should be accounted for if possible when looking at fufu preference.

Lafun

Lafun is a fibrous cassava powder that is reconstituted into a paste similarly to dried fufu in Nigeria. The method of production of lafun is different from that of fufu. In the traditional lafun preparation, fresh peeled cassava roots are cut into chunks and steeped for 3-4 days or until the roots become soft. Roots are then sun-dried for several days and milled into flour and reconstituted into a paste by addition of boiling water. Unlike fufu the fibres are still contained in lafun, which gives it a coarser texture (Cassava Biz, 2005). Lafun has similar quality criteria to fufu. In addition, a fast gelatinisation during cooking was appreciated.

Chikwangue and 'bâton de manioc'

Chikwangue or also called cassava bread and similar products such as 'bâton de manioc' are common forms of cassava consumption in Central Africa, in mostly francophone countries (*i.e.* Cameroon, Gabon, Congo). Chikwangue and 'bâton de manioc' are prepared by peeling, and chopping roots into chunks that are left covered in water (sometimes running water -- such as a stream or river) for about 2 days. Afterwards central fibres are removed, the pieces washed with clear water, squeezed and made into a smooth paste. The paste is then wrapped in young leaves (*Megaphrynium macrostachyum*, or other species of *Marantaceae*) bound with raffia and boiled (O'Brien et al., 1992; Agbor-Egbe and Mbome, 2006). Boiling/steaming can be carried out in one or more stages: sometimes the product is pregelatinised in the first cooking and later further cooked. Odour, taste, elasticity and stickiness were important criteria (Adoua-Oyila et al., 1995). These different processing variants conveydiverse sensory characteristics to chikwangue and 'bâton'. Interestingly, preferences of chikwangue were influenced by gender, tribe, location, urban or rural origin whereas other products did not show such influence (Treche et al., 1995).

Solid state fermented products

Solid state fermented products comprise agbelima, gari and attieke (Table 1). Peeled roots grated into a mash (solid state) are allowed to ferment for various durations. Most times, fermentations are spontaneous. Durations of fermentation vary from a few hours to several days. The products may be dried (semolina form. *i.e.* gari and attieke) or wet (*i.e.* agbelima).

Agbelima

Agbelima is a fermented cassava meal widely consumed in Ghana, Togo and Benin. The first steps of processing include peeling, grating and fermenting such as most cassava fermented products. However contrary to the gari and fufu products that undergo spontaneous fermentation, the preparation of agbelima incurs addition of a traditional inoculum called kudeme, which aids fermentation and breaks down the texture of the product through the activity of a number of tissue degrading enzymes (Dziedzoave et al., 1999). The product is

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mostly consumed as a wet form. Quality specifications for agbelima were developed (Dziedzoave, 1996; Dziedzoave et al., 1999; Dziedzoave et al., 2000). Three important criteria of acceptability were bright white colour, smoothness and taste.

Gari

Gari is a semolina-like cassava product with a slight sour taste that is made by peeling, grating roots followed by fermentation and/or pressing and roasting & drying. Gari is widely consumed in West Africa in particular. Gari is processed in a variety of ways and may have varying levels of fermentation and granular size. In Benin, there are numerous qualities and types of gari and some types are made from sweet cassava varieties and are not fermented. In Nigeria, gari is the main staple food from cassava and accounts for more than a third of the cassava produced. Gari can equally be eaten as it is, or sprinkled on other food or diluted into water/milk with sugar or reconstituted with boiling water into a thick paste (called eba in Nigeria and piron in Benin). Gari quality is judged by its swelling capacity, colour, particle size, moisture content, and a slight sour taste was appreciated (Blanshard et al.,1994; Achinewhu et al., 1998; Oduro et al., 2000; Irtwange and Achimba, 2009; Ray and Sivakumar 2009; Owuamanam et al., 2010; Owuamanam et al., 2010).

Attieke

Attieke is a semolina-like product made from cassava. The initial steps of preparation are similar to gari (peeling, rasping, fermentation & pressing, sieving) but the latter steps involve a steaming in place of roasting. In order to store longer it could be dried (using sun or artificial

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drying) and later rehydrated by another steaming. Attieke has a slight sour taste and is similar to couscous in appearance (Djeni et al., 2011). It is very popular in Ivory Coast and consumed in many countries in West Africa. Djeni et al., 2011 reported that quality samples were homogenous (granules of equal sizes), did not have extraneous matter, were not too sour, had a pleasant odour and were sweet. Nimaga et al., 2012 showed that the fermenting conditions (type of starter; quantity of starter; fermentation time) significantly influenced the sensory characteristics of attieke and therefore on its acceptance. More research will be needed to understand the effect of cassava variety on the quality and sensory characteristics of attieke.

The main quality and acceptance criteria differ for different cassava products. The products are found in different forms: dry (gari; lafun, fufu) or wet (fufu, agbelima, chikwangue, attieke); paste (fufu, agbelima, gari) or granulous (gari; attieke) and flour like (HQCF, starch, fufu and lafun). This may explain why the criteria for acceptance vary. Overall, independently of the product, the two main quality criteria are lack of extraneous matter and homogeneity (*i.e.* colour, texture, taste).

Texture is a very important quality criterion for acceptance of cassava products. Paste or dough are most liked when they are smooth (or soft), elastic and sticky. For gari an important criteria is the ability to swell when made into eba or piron (by adding boiling water). Swelling power is also important for attieke.

Colour criteria (e.g. cream; white or yellow) vary according to the nature of the product. A gari made with palm oil would have an acceptable yellow colour whilst a gari made with local roots would be white or cream in appearance.

Overall flavour and smell to be acceptable to the end-users should be typical of the product but they should not be too strong because these products are used as staples to accompany food that will give the flavour (vegetable; sauce; meat; fish) to the dish. In some products and for some consumers a slight acid taste is appreciated (*e.g.* gari, attieke). In other products (*e.g.* fufu) and for other consumers, a taste or smell close to neutral is preferred.

HOW DO WE RELATE PHYSICOCHEMICAL CHARACTERISTICS TO SENSORY PROPERTIES AND CONSUMER ACCEPTANCE?

Cassava traits

A trait is a distinguishing quality or characteristic, attribute, feature, quality, property. For breeders a trait refers to a genetically determined characteristic that is associated to a specific phenotype. There are more than 200 traits associated to cassava phenotype, and these can be classified into five different types: agronomic; biotic stress, morphological, physiological and quality traits.

The main quality traits for cassava have been reorganised and are listed below (Table 2).

Cassava chemical composition

Cassava traits are closely linked to chemical composition and sometimes confounded with it. The chemical constituents comprise the macronutrients (carbohydrates: starch, pectins, sugars, fibres, organic acids and ash) and the micronutrients (vitamins, minerals). There are also anti-nutritional compounds (*i.e.* cyanogens). In addition quality traits may include textural properties, dry matter and product yield.

Macronutrients

Of the nutrients in cassava, carbohydrate, and in particular starch is the main component (85% on a dry weight basis) (Sánchez et al., 2009; Sayre et al., 2011) and is the main constituent that will influence physicochemical characteristics, functional and sensory properties, and consequently it will affect end-user acceptability. Starch is formed of amylopectin (70-80%) and amylose (20-30%). Starch quality and properties are linked to the amylose/amylopectin ratio. There is also a genetic link between starch content and dry matter content. Sánchez et al., 2009 working on 4044 cassava genotypes coming from different parts of the world recorded variable dry matter contents varying between 14 and 48% and starch contents between 65 and 95% on a dry weight basis. Amylose varied between 15.2 and 26.5 with 20.7% on average. Starch quality and quantity is governed by genes and thus the variety will influence but also the environment (climate and ambient temperature; rain or drought, soil type, use of fertilisers and geographical area).

Table 3 summarises the proximate, vitamin and mineral composition of cassava roots.. Cassava contains more carbohydrates than potatoes, and cereals such as wheat, rice, maize and sorghum. The main simple sugars are sucrose, glucose, fructose and maltose. According to Sánchez et al., 2009 total sugars and reducing sugars in cassava roots were 3.7% and 1.2% on average (with variations between 0.2% -18.8%) and 0%-15.7%), respectively.

Protein and lipid contents were low in cassava (respectively less than 3.5% and 0.5%), and showed that cassava roots had poor nutritional value. The lipid content was low compared to maize and sorghum but higher than potato and comparable to rice. (Montagnac et al., 2009).

Considering the protein content, Yeoh and Truong, 1996 demonstrated that the classical nitrogen-to-protein conversion factor (6.25) was not valid when working with cassava and that the real conversion factor is around 3.24. This indicates that the levels of protein given in Table 3 should actually be even lower. In contrast to cassava roots, maize and sorghum whole grain have about 10-12% (dry basis) of protein. Half of the protein content in cassava roots consists of proteins whilst the other half consists of amino acids. Some essential amino acids, such as methionine, cysteine, and tryptophan are found in very low amounts however roots contain substantial amounts of arginine, glutamate and aspartate (Montagnac et al., 2009**)**. Non-protein components are nitrite, nitrate and cyanogenic acids. Cyanogenic potential varied between 14 and 3274 ppm, with 340 ppm on average (Sánchez et al., 2009). The protein content in the leaves was 30% in fresh weight and showed that leaf protein could be a supplement to the roots that had very low protein content. According to Chavez et al.(2000)

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there should be space for genetic improvement in protein in cassava roots by means of genetic engineering.

Minerals and vitamins

Cassava roots contain calcium, iron, potassium, magnesium, copper, zinc, and manganese in amounts comparable to those of many legumes except soybeans.

According to Montagnac et al., 2009, using a compilation of several references on cassava, calcium content in roots comprised between 16 and 176 mg/100 g fresh weight, and calcium levels were relatively high compared to that of other staple crops (Montagnac et al., 2009) (Table 3).

Average levels of iron and zinc were 9.6 mg/kg and 6.4 mg/kg (dry weight basis) respectively (Chavez et al., 2000). These were very low concentrations according to Burns et al. (2012**)**. Studies to improve the levels of iron and zinc in cassava have encountered some challenges because of the very low baseline levels and current biofortification programmes for cassava are mainly aiming at enhancing carotenoid levels.

Provitamin A carotenoid contents were variable but overall quite low in roots compared to leaves (factor of about 1000 times less) (Montagnac et al., 2009**)**. Cassava roots also contain low amounts of the B vitamins (thiamine, riboflavin, and niacin) that may be lost during processing (Table 3). Montagnac et al., 2009 concluded that mineral and vitamin contents are mostly lower in cassava roots than in most cereals, legumes and some other root and tuber crops. Their nutritional content would require some improvement.

In addition to the agronomical traits, quality traits such as reduced cyanide content, starch and protein, micronutrient (iron, zinc and vitamins) content and quality are listed in Table 3.

Breeding to improve cassava traits (*i.e.* using genetic engineering or conventional breeding) has to be watched closely because modifications in a particular trait might have impact on other characteristics of the roots (epistasis). Cach et al., 2005 reported that there is paucity of knowledge on the inheritance of agronomic traits in cassava and the importance of epistasis. It however appears that epistasis is very likely to occur for non-negligible number of traits in cassava. In particular, the authors suggested that dominance of genes play an important role in complex traits such as root yield.

Starch, dry matter and influence on texture

Texture of cassava products is a critical factor for consumer acceptance. According to the local consumers of cassava products in Nigeria, texture is the most important criterion for acceptance of the products before taste and smell. Because cassava products are not eaten by themselves, the side dish brings the flavour whilst the cassava dish brings the texture to the dish.

Most of the textural change in roots and tubers during ripening or processing are related to pectin and starch content and composition, *i.e.* amylose/amylopectin ratio.

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Starch content and composition (amylose/amylopectin) influence the texture rather than the taste and other sensory attributes. Texture is an important characteristic that will impact consumer acceptability and preference for products (Ross et al., 2011). However texture is linked to several elements: genetics, environment and processing, and the factors that are responsible for texture in cassava are still not fully investigated.

As for potato (Taylor et al., 2007; Ross et al., 2011) a large number of factors influences cassava texture such as starch content, starch distribution within the root, starch swelling pressure, cell size, cell wall structure and composition and its breakdown during cooking (Beleia et al., 2006). Texture is therefore likely to involve many genes.

The cooking process will have a fundamental effect on the starch by making it gelatinise. Gelatinisation will therefore have a critical effect on the texture of the cassava product. Sanni et al., 2004 reported significant correlations between sensory texture of fufu and some pasting properties of cassava starch (by using Rapid Visco Analyser): a negative correlation with peak viscosity or starch stability, and a positive correlation with setback value for the fufu samples were observed.

Dziedzoave et al., 1999 working on agbelima showed significant correlations between sensory descriptors scored by panellists (36 people using a 4 point intensity scale) and physicochemical measurements: smoothness was related to particle uniformity and a weak correlation was found between cohesiveness and starch content. Padonou et al., 2005 showed that there was a significant relationship between mealiness and firmness of boiled cassava roots measured using

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a texture analyser and that firmness was significantly correlated with apparent viscosity after pasting (using a Rapid Viscosity Analyser). Mealiness also has been shown to generally increase with dry matter content. There have been attempts to correlate starch content or starch properties with the mealiness of boiled potato. It was reported that starch swelling resulted in softening potato cell walls however no clear relationship was found between starch content and starch properties with mealiness. On the other hand, studies on potato clearly show a relationship between pectins content and mealiness (Ross et al., 2011). On cassava, the relationship remains to be proven.

Waxy mutant cassava varieties have been developed by CIAT in collaboration with other research institutes. These genetically modified varieties have very low amylose content and could be used in the making of industrial products with specific gelatinisation properties and specific uses (Zhao et al., 2011).

Sensory attributes that drive consumer acceptance such as cohesiveness, smoothness, swelling, and in some extent mealiness are all linked to the starch composition and gelatinisation process.

Pectin and influence on mealiness and firmness

Hongbété et al., 2011 found that although starch might have an influence, pectins are more likely to be the major biochemical factor in relation with mealiness. Jarvis et al., 2003 commented that starch swelling pressure played a role in cell separation in cooked vegetables, but degradation of the pectic polymers involved in cell adhesion was also necessary for cell

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separation. These findings are in accordance with Favaro et al., 2008 who worked on two varieties of cassava that had different cooking times. Softening of cell walls during cooking was studied in relation with intracellular compounds such as cations (Ca2+ and Mg2+), phytic acid and pectins. It appeared that the cultivar with the longer cooking time had lower level of cations, phytic acid, and higher levels of chelator-insoluble pectic polysaccharides. It is therefore suspected that pectins have a major role in mealiness. Pectins play an important role in cell adhesion in fruits and vegetables and mealiness can result from a high degree of cell separation due to pectin degradation or solubilisation (*i.e.* during cooking) commented Jarvis et al., 2003. Solubility of pectins increased with temperature and would lead to a decrease in the shear force (compression) in cassava roots (Menoli and Beleia, 2007). Hongbété et al., 2011 noted that it is likely that mealiness is associated to pectins in cassava. A recent study on sweet potato indicated that two enzymes: pectin methylesterase (PME) (that catalyses de-esterification of pectin into pectate and methanol) and amylase (starch degrading enzyme) played an important role in firmness: a low temperature blanching preserved some PME activity and increased the firmness of the gel and decreased free starch rate (He et al., 2014). PME and cellulase appeared to play an important role in the softening of cassava roots during fermentation and PME and α-amylase production were shown to increase during fufu fermentation. (Oyewole and Odunfa, 1992). PME is an interesting enzyme because it can have two opposite effects: one is a contribution to the firmness of the cell wall (He et al., 2014) by producing unesterified carboxyl groups that interact with calcium ions forming a pectate gel and the other is to contribute to cell wall softening (Oyewole and Odunfa, 1992) by releasing a proton that may induce activity of cell wall hydrolases.

Mealiness is also influenced by environmental factors. Hongbété et al., 2011 reported that rainfall before harvest had a direct effect on lowering dry matter and decreasing mealiness in boiled roots. In addition to genotype factors, environmental factors could significantly influence sensory perception of cassava products. Mealiness or friability of boiled roots is an important attribute for consumer acceptance (Hongbété et al., 2011) since boiled or fried root should not be too hard for the consumer to eat.

Sugars and influence on taste

Djeni et al., 2011 showed that were a strong correlation between sweetness and reducing sugar content in attieke. Therefore the sweetness perceived in cassava products is probably directly linked to their concentration in reducing sugars.

Sweetness is often a driver of food acceptability in general. Little work has been reported on acceptability of cassava related to sweetness. Quality of fresh cassava is evaluated by farmers, traders and processors who sell or buy the fresh roots. Working with CMD (cassava mosaic disease) and CBSD (cassava brown streak disease) resistant varieties, Saleh et al., 2004 sought to understand acceptance of these improved resistant and high yielding varieties compared to local breeds that were prone to common virus disease and pests and low yields. Clones (ZNZ/98/036; ZNZ/98/034 and ZNZ/98/084) were selected by the farmers because of several preference characteristics including disease resistance, high root yielding, dry root matter

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content and sweetness (evaluated by farmers on a 5 point-scale), (Saleh et al., 2004). Sweetness was included as a criterion for clone selection. Another study by Tumuhimbise et al., 2012, showed that the second more desirable characteristic in early bulking storage cassava cultivars was sweetness (the most desirable characteristics being high dry matter content). These findings indicate that sweetness is indicated as one of the drivers for acceptability of cassava by farmers.

Carotenoids and influence on root flesh colour appearance, taste, smell and texture

Most cassava grown in Africa is of white or cream flesh colour. Recently biofortified varieties that have a yellow flesh colour due to increased provitamin A content have been introduced. Since these novel varieties have a different but visible trait (the yellow colour) (Njoku et al., 2011) understanding of the perception and acceptance will be very important. These cassava varieties are called ‘biofortified’ (Figure 4A). Biofortification is the process by which micronutrients of interest are increased without sacrificing important agronomic traits such as yield and resistance to environmental stressors. The aim of biofortification is tackle micronutrient deficiency or also called hidden hungerbecause of the lack of overt clinical signs in people who are deficient. Increase in micronutrients in the crop along with improved agronomic traits can be achieved through conventional breeding, by improving agronomic practices (*i.e.* fertilisers, water management), or by genetically engineering or modification techniques (De Moura et al., 2015). Yellow provitamin A cassava varieties were first released in Nigeria and in DRC in 2011-12 (Bouis and Welch, 2010).

Carotenoid content was found to be highly correlated with the colour of cassava flesh (Chavez et al. 2000; Ceballos et al., 2013; Bechoff et al, 2015): white, cream, yellow, deep yellow, orange root colour corresponded to values of ≤1; 4; 6; 8 and more than 12 (max. 25.8) ug/g fresh weight basis respectively.

Total carotenoid content and colour intensity were strongly and positively associated, suggesting that simple screening based on visual scoring of colour was satisfactory for initial selection of the roots of cassava clones with relatively high total carotenoid content (Sánchez et al., 2006; Blagbrough et al., 2010). Sánchez et al., 2014 working on more than 3000 samples demonstrated that there was a linear correlation between colour measured using near-infrared spectroscopy (NIRS) or visible colour chromatometer and carotenoid levels. NIRS or chromatometry can therefore improve selection protocols by allowing faster carotenoid determination from cassava clones that might be useful in screening stages for breeding (Sánchez et al., 2014). Ceballos et al., 2013 managed to develop a rapid cycling recurrent selection for high carotenoid content cultivars that was reduced from the ordinary eight years to three years. Data clearly showed that clones with higher carotenoid levels were obtained at each cycle of selection. In addition to gaining carotenoids, some clones were also gaining in dry matter content. This is an interesting finding because it shows that the genetic link between high carotenoid and low dry matter content could potentially be overcome in cassava using selective breeding.

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However some local cassava products such as gari can be prepared with palm oil containing carotenoids, which also transfers a yellow colour (and carotenoids) to the product (Bechoff et al., 2015b). Bechoff et al., 2014 working on local (white), with and without palm oil, biofortified yellow cassava fufu and eba products (TMS 01/1371; 01/1368; 01/1412) also found that biofortified products were acceptable (with a score ≥ 7 (like moderately)) to the local Nigerian consumers (n = 122). The gari prepared with palm oil and with yellow cassava do not significantly differ in terms of appearance (Figure 4B). Therefore although yellow colour is a visible trait in the root, the final product (gari with palm oil) does not differ in colour from the product people are used to consume. The vitamin A activity of palm oil gari and biofortified gari of the same colour respectively were about 300 and 200 RAE (Retinol Activity Equivalent), respectively (Bechoff et al. 2015b). Oparinde et al., 2012 worked on the acceptability of conventionally bred biofortified cassava products (eba and gari) in West and Eastern parts of Nigeria. The authors found that biofortified yellow cassava was acceptable to the consumer compared to the traditional local (white varieties) and white with added palm oil. Varieties used were TMS 01/1371 and 01/1368.

Genetically Modified (GM) cassava with high provitamin A content (of yellow colour) was tested for consumer acceptability in Brazil (González et al., 2009). Although the acceptability of GM cassava was high (using the willingness-to-pay approach), the research suggests that the varieties will be more acceptable to the population if they were obtained by conventional techniques. This is because a small number of interviewees had resistance against GM crops because of ethical and health risk concern. Further investigation suggests that a confounding factor is that the GM crops had very low dry matter content (González et al., 2009) and this might have been a hurdle to consumer acceptance. More research on the consumer acceptance of GM cassava with high carotenoid content might be needed.

Contrary to gari, fufu is not prepared with the addition of palm oil. Therefore biofortified yellow fufu had a different trait to the local and white fufu. Bechoff et al., 2014 also tested yellow fufu from biofortified cassava in South-West of Nigeria and found it acceptable. The authors showed that the main drivers (selected by the consumers) for acceptance of the products were 'smoothness'; 'yellow colour'; 'good for eye sight'; 'good for health' and 'mouldable'. Sourness had a negative effect on consumer acceptance. Interestingly, yellow colour was an acceptance criterion; the colour might have been associated with health benefits of biofortified products in the mind of the consumers. Moreover, coloured products were more acceptable than white local products the people were accustomed to. However, yellow cassava roots had lower dry matter and this may lead to lower acceptance by processors due to the lower yields of gari compared to white cassava.

Talsma et al., 2013 tested the acceptance of boiled biofortified cassava 97/1170 with school children in Kenya. Biofortified cassava was preferred over the local variety because of its soft texture, sweet taste and attractive colour. Knowledge about biofortified cassava and benefits to health had strong influence on the consumer behaviour. The authors reported that children (30) and caretakers (30) perceived a significant difference between the taste of the yellow cassava and the white local one (ex-Mariakam) that was boiled. The difference was perceived independently of the colour. This finding was in agreement with Bechoff et al., 2014 who found that people are able to distinguish between biofortified and local cassava products in a blind test.

While for cassava there is no published work that relates carotenoid content to visual rating of colour, this has been demonstrated for other root and tuber crops such as sweet potato (Tomlins et al., 2012).

In summary, increasing the carotenoid content did not only influence colour but also softer texture and sweeter taste. Biofortified cassava products developed by conventional breeding methods is more acceptable to consumers in hedonic and willingness to pay tests. GMO biofortified cassava product was less acceptable but may be confounded with a lower dry matter content. Yellow cassava products are already commonly consumed due to the addition of palm oil containing provitamin A.

Minerals (zinc and iron) and taste

Zinc and iron deficiencies are two other major micronutrient deficiencies aside vitamin A. Chavez et al., 2000 initially suggested that not only the carotenoid content of cassava varieties can be improved but also their content in zinc and iron. The levels of zinc and iron were measured in existing cassava varieties and authors suggested that cassava varieties could be adapted to deliver higher levels of zinc and iron that could help tackling micronutrient deficiencies. The anti-nutrients (e.g. phytates; tannin) present in these crops and deterring the absorption of iron and zinc will also have to be taken into account. However a modification in

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the anti-nutrient content can also affect the plant metabolism and has to be watched carefully (Bouis and Welch, 2010). Later trials have shown that the biofortification of cassava with iron and zinc is more complex than expected and therefore most likely requires the input of genetic engineering. Genetically Modified techniques are actively pursuing the enhancement of iron and zinc in cassava (*i.e.* Danforth Center, USA) and conventional biofortification programs for cassava have now focused solely on carotenoid biofortification (Dufour D. Pers. Comm. 2015). Minerals were not found to be associated with visible traits in other crops (*e.g.* biofortified high iron beans) and similar findings are likely with cassava.

Cyanide and bitter taste

High cyanide content in cassava has traditionally been associated with bitter taste (Bokanga, 1994). A study by Chiwona-Karltun et al., 2004 showed that bitter taste was correlated to cyanide level when tasted raw by farmers. Saleh et al., 2004 also reported a significant correlation (R = 0.94) between sweetness perceived by the farmers and cyanide content in the roots and this would be attributed to bitterness: the more bitter the varieties the less sweet they would be perceived. There is still a debate however on whether the cyanide level could be directly linked to the perceived bitterness. King and Bradbury, 1995 commented that the bitterness was not directly linked to the linamarin content but rather to another compound called isopropyl-β-D-apiofuranosyl-(1 6)-β-D-glucopyranoside (IAG, structure I). Hongbété et al., 2011 working on boiled roots did not find a clear correlation between bitterness and cyanogen potential. The authors commented that bitter cultivars often contain more soluble sugars that sweet ones do and therefore these cultivars were not scored bitter by the panellists. But overall most studies prove that bitterness is correlated to cyanogenic potential.

Literature was scare on the consumer acceptance for bitter taste and may in part be related to ethical concerns in conducting such tests. In general bitter taste is not unanimously appreciated by consumers. Bitterness tends to be more of a negative taste than a positive one. It seems that bitter taste might not be acceptable to the cassava consumer also because of the association with cyanide risk. However research studies (Bokanga, 1994; Chiwona-Karltun et al., 1998; Mkumbira et al., 2003) showed that farmers clearly preferred bitter varieties because they were less susceptible to pests and diseases and also to theft. Breeding studies should consider liking of farmers that prefer high cyanide varieties. Adequate processing steps may be a sufficient measure to detoxify cassava to a safe level for consumption and produce a safe and non-bitter cassava product.

Organic acids, fermentation and acidic smell and taste

Fermented sour taste is an important sensory attribute for many fermented cassava products and is linked to the presence of organic acids formed during lactic fermentation. Although formation of organic acids might be related to the starch content and composition, it is mostly depending upon fermentation duration and temperature and microflora present in the cassava.

Fermentation is a common practice for cassava, especially in Africa (Westby, 2002). It is a way of producing a safe product that has a longer shelf-life as well as meeting consumer preferences: low pH inhibits growth of most pathogen bacteria. During fermentation, sugars

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are converted into organic acids by indigenous flora of lactic bacteria and yeast present in cassava mash.

Owuamanam et al., 2010 demonstrated that the low pH obtained during fermentation for gari was due to the presence of organic acids such as lactic, acetic, propionic, pyruvic acids. Slightly acid cassava products are appreciated by consumers (Owuamanam et al., 2010).

Working with agbelima from Ghana, Dziedzoave et al., 1999 showed that there were significant correlations between sensory intensity rated by 36 panellists (using a 4 point intensity scale) and physicochemical measurements: sourness was strongly correlated with pH (negatively) and with acidity (positively). Djeni et al., 2011 further demonstrated that acidity of attieke samples was directly proportional to the amount of organic acids present. Lactic, acetic and oxalic acids were the most common and in greatest amounts in all the samples analysed. Lactic acid was the major organic acid and amounts were found to vary significantly in different attieke types. Similarly to Dziedoave et al., 1999, strong correlations were found between sourness and concentration in main organic acids in the product.

Sourness of the product is closely dependent on the fermentation process (microorganisms *i.e.* lactic bacteria and indigenous flora, temperature, oxygen and time of fermentation). But it is also somehow affected by starch level (and composition) in the cassava roots (amylases will degrade starch into sugars that will then be converted into organic acids). The relationships between starch level and sourness of the product are still being investigated.

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Post Physiological Deterioration and influence on taste and appearance

Post-harvest Physiological Deterioration (PPD) is a major issue for the preservation of cassava roots and consequently their marketing: after 2-3 days under ambient conditions, roots start to deteriorate (Westby, 2002; Reilly et al., 2004). A black-blue to black vascular discoloration (vascular streaking) indicates the start of PPD that then spreads to the parenchyma (Blagbrough et al., 2010). Reilly et al., 2004 showed that PPD was strongly linked to an oxidative burst that resulted in biochemical changes in the root and led to its deterioration. PPD was accompanied with increase in respiration, ethylene, diterpene biosynthesis, enzyme activity (e.g. PAL; CAT; PPO; invertase; peroxidase) changes in membrane lipid and sterols, protein synthesis, and gene expression (Beeching et al., 2002). PPD has been associated in particular with the production of compounds called hydroxycoumarins (esculin, esculetin, scopolin and scopoletin) (Buschman et al., 2000). Scopoletin in particular was shown to have an important role (Sánchez et al., 2013). The more tolerant cultivars to PPD had higher amounts of scopoleptin. Scopoletin levels also increased during PPD, suggesting that scopoletin must be involved in reducing deterioration rate at the initial stage of PPD (Uarrota and Maraschin, 2015).

PPD has been shown to affect the taste and appearance of cassava products. Two varieties, one susceptible to PPD (TME-1) and one resistant (improved TMS 30572) were compared over two consecutive years (Aigbe and Remison, 2009). Gari products were prepared from the two varieties. Consumer acceptability (for odour, taste, texture and colour) was significantly lower in the rot susceptible variety compared to the improved variety. Hence rotting is proven to be a negative driving factor for the acceptability of gari products. A limited number of people (n =

28) were interviewed however. The results of this experiment showed that high root rot incidence of a cassava genotype in the field may reduce consumer's acceptability of the gari produced from it. Genetic susceptibility of a variety to rotting is also likely to influence the consumer acceptability.

Cassava age and taste, texture, colour

Root age is a trait that can significantly influence on the quality and composition of roots. Most common age for harvesting cassava is 12 months after planting. However different varieties have different optimal ages for harvesting. Time of harvesting is linked to optimal maturity characteristics of the roots such as bulkiness, mealiness or cooking quality of roots explained Apea-Bah et al., 2011. Gari was prepared from four different cassava varieties: Afisiafi, Tekbankye, Abasafitaa and Gblemoduade that were harvested each month from 10 months until 15 months after planting. Consumer acceptance was tested using a 9-point hedonic scale (n = 24 assessors) for taste, colour, crispness, aroma, appearance and overall acceptability. Taste was significantly affected ($p<0.01$) by age at harvest. All the other sensory attributes were significantly affected ($p<0.01$) by age at harvest and variety. Gari prepared from older harvests (14 months and 15 months) were preferred by assessors to gari from younger harvests. Root age was shown to be an important factor on the acceptability of cassava products.

WHAT ARE THE GENETIC DRIVERS FOR THESE PHYSICOCHEMICAL CHARACTERISTICS?

Cassava phenotype is controlled by genotype and environments. If we could identify the genes controlling quality traits, then we may be able to modulate the expression of these genes by either using conventional breeding or genetic engineering to make cassava more appealing to the end-users and with better nutritional quality traits.

A first step in identifying the genes is to find the parts of the genome that are related to specific quality traits: quantitative trait loci (QTL) are map regions of the genome (DNA) that contain genes specifically related to a quantitative and qualitative trait (*e.g.* starch content; starch composition etc.). QTL are used as an early step in identifying and sequencing the actual genes underlying trait variation.

The years 2000-2005 marked research on the stabilisation phase for the genetic transformation of cassava, whilst from 2005 research moved on unto more specific improvements aimed at targeted traits as quality traits such as starch, cyanide and protein (Liu et al., 2011).

Starch

Amylopectin/amylose ratios are linked with starch quality and functional properties. Starch synthesis is regulated by three key enzymes: 1) AGPase; 2) starch synthetase and 3) starch branching enzyme that have been successfully cloned. It was reported that AGPase in particular can contribute to the conversion sugar to starch. This means that transgenic plants with enhanced AGPase activity can result in improved cassava yield and increased starch content (Liu et al., 2011)

The texture of cassava based products is an important criterion of quality and often linked to starch pasting viscosity. Thanyasiriwat et al., 2013 tentatively identify loci and candidate genes associated with the starch pasting viscosity. Fifteen Quantitative trait loci (QTL) were identified.

Candidate genes were identified within the QTL peak regions. The authors concluded that 'the loci identified could effectively help to improve cassava starch quality. Alleles of candidate genes should be further studied in order to better understand their effects on starch quality traits'. Pootakham et al., 2014 further confirmed the position of controlling starch pasting properties on quantitative trait locus previously identified, and discovered a novel QTL associated with starch pasting time on Linkage Group (LG) 10.

Dry matter

A link exists between starch and dry matter content in cassava: the greater the starch content; the higher the dry matter content.

Balyejusa Kizito et al., 2007 identified QTL controlling cyanogenic potential (CNP) and dry matter content (DMC) in cassava. Cyanogenic potential and dry matter content both had a genetic component that was heritable. This study is a first step towards developing molecular marker tools for efficient breeding of CNP and DMC in cassava. De Oliveira et al., 2012 studied the markers for different agronomic characteristics of cassava including the fresh root yield (FRY), amylose content (AC), dry matter content (DMC), and starch yield (SY). The authors found that most traits (excepted AC) had good heritability and could therefore be used to accelerate selection of high dry matter cultivars and with high yield. Chen et al., 2012 stated that in cassava breeding one of the major goals was indeed to increase root yield. The authors identified repeatability-detected-QTL (rd-QTL) for three phenotypic traits (fresh root yield, root dry matter content, and root starch content) in cassava. Twenty-five of these rd-QTLs were associated to markers, and this would facilitate the breeding selection for fresh root yield, dry matter content and starch content (Chen et al., 2012).

Pectins

Ross et al., 2011 working on reengineered potato demonstrated that overexpression of the gene PEST1 that is involved in Pectin Methyl Esterase (PME) activity resulted in transgenic potato significantly firmer than the control (wild type). There was a clear link between PME activity and firmer texture; reduced level of pectin methylation in the over-expressing transgenic lines was associated with a firmer processed texture. Because of the genetic proximity between potato and cassava, the same gene is likely to also regulate the production of PME in cassava and manipulation of the gene may result in modulating the firmness. More research is needed to investigate the relationships between firmness and PME in cassava.

Proteins

Cassava root has very low protein content. As a result high consumption of cassava if not complemented with other sources of protein may result in protein malnutrition.

Akinbo et al., 2012 suggested that the reason why root protein content is low is the breeding selection process that has over the years selected cassava with high fresh yield and disease resistance as opposed to nutritional characteristics such as protein content. Akinbo et al., 2012 believed that increasing protein content in cassava root will improve its usefulness by transforming it into a more complete food source especially in countries where malnutrition is predominant. There have been some efforts to improve cassava protein content. Wild cassava

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species (*Manihot esculenta ssp flabellifolia*) from Brazil contain significant amounts of protein and have been examined. A cross between wild species and an improved cassava variety resulted in a hybrid that allowed the identification of QTLs for root protein. In addition a screening of cassava varieties (Chávez et al., 2005) from various parts of the world indicated that many clones from Central and South America had higher protein levels in the roots, probably as a result of the transfer of genes from wild relatives found in that part of the world. The diversity of protein content found in nature gives confidence that there is scope for cassava with improved protein content to be developed. Protein content could be improved - at least in leaves - in transgenic cassava that expressed an artificial storage protein under the control of CaMV 35S promoter (Liu et al., 2011). There is hope that a better understanding of the genes linked to protein expression will allow to produce cassava varieties with higher protein content in the future.

Vitamin A and β-carotene

Most of the varieties containing provitamin A are currently obtained by conventional breeding. Although there have been some efforts to produce genetically modified cassava with high carotenoid content these have not been adopted because of epistasis - association between different genes (*i.e.* low dry matter content linked to high carotenoid content -- (Failla et al., 2012) which rends the varieties moist and therefore less acceptable, and also concerns directly related to genetic modification. In addition, the current genetically modified varieties do not present higher levels than biofortified varieties obtained by conventional breeding (Failla et al., 2012) and their yields in farmers' field have not been tested or results made publicly available.

In recent years, the progress in genomics and sequencing has allowed to understand better where carotenoids are located on the genome using QTL approach. QTL can now be used in breeding programs that target carotenoid accumulation in plants (biofortification) (Giuliano, 2014).

Sequencing of potato and tomato has revealed several genes involved in carotenoid biosynthesis. In both plants, phytoene synthase (PSY) is encoded by three genes, two of which expressed in most tissues (PSY1 and PSY2). In cassava, PSY is also a key regulator of carotenoid accumulation and its expression correlates with high carotenoid content (Giuliano, 2014; Welsch et al., 2010). A single nucleotide variation (SNP: single nucleotide polymorphism) results in overexpression of PSY and significant increase in level of carotenoids in cassava. Such variations in the gene can be obtained either by conventional breeding or genetic engineering commented Welsch et al., 2010.

Rabbi et al., 2014 found QTL specifically related to flesh colour and hence carotenoid content. The authors reported that the gene related to carotenoid content in cassava is likely to be PSY2, in accordance with the two studies above.

Cyanide

Several studies have looked at the genetic mapping of cyanide related genes (Balyejusa Kizito et al., 2007; Whankaew et al., 2011).

Balyejusa Kizito et al., 2007 stressed the fact that a trait such as cyanide level is highly influenced by environmental conditions. However the cyanide trait was proven to be heritable.

Quantitative trait loci (QTL) on two different linkage groups controlling cyanide potential (CNP) were identified. It appears that one QTL for CNP and one QTL for dry matter content mapped near each other, suggesting pleiotrophy and/or linkage for both traits. Whankaew et al., 2011 working with low and high cyanide cultivars also identifying QTL responsible for cyanide (CN): five QTL underlying CN were detected. Among all the identified QTL, CN09R1 was the most significantly associated with the CN trait and explained the greatest percentage of phenotypic variation. Both authors concluded that QTL can provide useful markers to assist in cassava breeding and studying genes affecting the trait. The genes responsible for cyanide in roots are under investigation. Liu et al., 2011 commented that overexpression of hydroxynitrile lyase can decrease acetone cyanohydrin content in roots. Reengineered cassava with cloned hydroxynitrile lyase had reduced cyanide level after processing; in fact, the total quantity of linamarin and lotaustralin did not change but the ability of cassava to reduce acetone cyanohydrin and consequently cyanide greatly increased. Therefore modulating the expression of hydroxynitrile lyase had an influence on the cyanide level in roots.

Physiological Post-harvest Deterioration (PPD)

It has been clearly demonstrated that the biochemical changes that occur during PPD are linked to a change in gene expression (Beeching et al., 2002). Reilly et al., 2004 affirmed that reducing PPD through conventional breeding will be a challenge with cassava because of the existing link between dry matter and PPD. The authors suggested that genetic engineering might be a better option. Cortés et al., 2002 tentatively identified QTL for PPD in cassava and showed which major genome regions were implied in PPD. Later, Reilly et al., 2007 showed that many genes that play a role in cellular process and oxidative mechanism, stress response, programmed cell death, metabolism, biosynthesis and activation of protein syntheses etc. were involved into PPD mechanism. Morante et al., 2010 reported that waxy cassava varieties were resistant to PPD but the mechanism is still under investigation. Finally Uarrota and Maraschin 2015 showed that several compounds (high phenolic acids, scopoletin, proteins, carotenoids, and hydrogen peroxide, as well as the increase of the guaiacol peroxidase activity in non-stored cassava roots) could be used as potential biomarkers related to the tolerance of PPD.

DISCUSSION

This review seeks to explore the relationship between breeding efforts and end-user preferences in order to offer suggestions for future research. The review has focused on several areas being:

a) Acceptance criteria for end-users with respect to sensory characteristics of the different types of cassava products

b) Physicochemical characteristics (quality traits) of cassava and how these are related to sensory characteristics, and acceptance

Genetic drivers for these physicochemical characteristicsc)

The past successes of introduced varieties have been in the reduction of losses from pest and disease by the introduction of cassava that is resistant to African Cassava Mosaic Disease (Thresh et al, 1997) and this is thought to have saved between $1.2 and $2.3 billion per annum

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(1997 values). More recently, varieties resistant to Cassava Brown Streak Disease have been developed and released but it is too soon to determine the impact (M. Gowda, personal communication). New varieties have increased yields of fresh roots (from 5 to 10 tonnes per ha in the 1950's to between 10-15 tonnes per ha in 2002 (Nweke et al., 2002)). With a current production in Africa of 157 million tonnes per annum (FAOSTAT 2013), the increase in production with newer high yielding varieties could potentially be equivalent to an additional 30 to 60 million tonnes per year (estimate). However, the success regarding the acceptance of new cassava varieties by end-users has been difficult to measure, because there are few published results on this topic or attempts to measure the impact (Acheampong, 2015). Breeders, however, need access to knowledge to understand how improved cassava varieties might be perceived by end-users and how modifying cassava quality trait might affect processing ability, sensory characteristics and consequently consumer acceptance and market demand.

The types of cassava products had distinct sensory characteristics and these should direct breeding initiatives. In Brazil, Farmers Participatory Research Techniques have been reported to be effective mechanisms to identify crop constraints and may be useful for application to end user traits (Pires de Matos et al. 1997). A recent research study in Zambia looked at farmer preference, utilisation of improved cassava varieties and biochemical composition (Chiwona-Karltun et al., 2015). There was a clear relationship between variety use and biochemical composition (*e.g.* varieties used for local dish 'nshima' had high carbohydrate content). Similar studies are needed to understand how improved cassava varieties can be promoted for

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different product applications based on biochemical composition that links to quality traits. In our review, non-fermented cassava products (that were directly consumed) were either related to sensory characteristics associated with bland and texture or to the type of processing as in fried products. Non-fermented cassava products that were made into industrial products needed to meet specifications laid down in standards from the private sector. The specifications tended to relate to dry matter content, starch content, cyanide concentration, colour, foreign matter and microbiological levels. For products formed by water submersion, the criteria tended to relate to dry matter content, colour, texture and taste and odour being either related to fermented attributes or bland according to local tastes. Solid stage fermented products tend to be associated with attributes relating to sourness, swelling capacity, particle size and appearance.

Genes responsible for some of these traits are being investigated. Table 4 summarises the relationships between quality traits, possible genes associated and the effect of quality trait improvement on the sensory perception and end-user acceptance. Although some research has been carried out on some of the main quality traits of cassava, there are still many gaps. One of the hurdles for instance is epistasis. Epistasis between the different genes responsible for expressing specific traits is not well known; for instance the correlations between high dry matter content and high cyanogenic content or between low dry matter content and high carotenoid content. It seems that for the latter, the link between dry matter content and carotenoid content could be overcome since high carotenoid and high dry matter varieties have been successfully developed by CIAT (Ceballos et al. 2013). Some findings suggested that the

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link between PPD reduction and carotenoid content (and hence other antioxidants in the root) was not actually proven and that the concentration in scopoleptin seems to play a greater role than the colour or carotenoid content of the root in reducing PPD (Luna et al. 2014).

Recently, breeders are progressively changing the focus of their research to target specific particular cassava traits (Liu et al., 2011). In the future, the progress in genomics and breeding will help understand the make-up of cassava and also how to breed more efficiently and rapidly to obtain desirable characteristics. The progress should help ‘tailor’ varieties of cassava that will be adapted to specific products and with specific nutritional characteristics.

GAPS AND FUTURE RESEARCH OPPORTUNITIES

This review has explored current published work on cassava and end-user preference. The authors have identified gaps in knowledge which may help direct future breeding programmes and also enhance impact. Suggested gaps are as follows:

1) Can more be learned from past successes in introducing cassava varieties? New knowledge about the success and failures for farmers to adopt may provide new insights that can assist breeding programmes and understand impact which may be related to socioeconomic, gender and market issues. How would this be measured?

2) There is a paucity of knowledge regarding the size of the market for the key cassava products in Africa. The authors have made an estimate based on personal observations only. Research into understanding the market space that cassava

products occupy and future trends will be important in determining where the resource investment in cassava breeding will be needed. For example, in Africa there is increasing interest in diversification of cassava from direct food use to starch production, syrups, industrial adhesives, use in beer production etc. In addition, new varieties that can contribute to alleviating vitamin A deficiency have recently been introduced and impact will be enhanced if there is a better understanding of market demand.

3) The plant breeding initiatives will need to respond to new emerging technologies relating to farming, storage, processing (for example grating, pressing, drying etc.) and marketing.

4) A deeper understanding of competing products in the market space that cassava occupies will also assist plant breeders more accurately determine the traits to breed far. For example, cassava will compete with other staple products with increasing urbanisation as people migrate from rural areas.

5) Socioeconomic and gender analyses may be important to ensure that uptake meets the requirements of local communities and that uptake is equitable. Overall little work has been reported on the gender differences in the consumer acceptance rating of cassava products. Market interventions must take into account the difficult and challenging subject of gendered power relations which ultimately constrain women's benefits in markets more generally (Forsythe et al., 2015). A thorough

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gender analysis is required with reference to end user preferences in order to question assumptions of de facto inclusiveness prevalent in development narratives about markets.

6) Intellectual property rights issues may be critical so that communities in Africa can benefit from local knowledge they have.

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Table 1. Acceptance criteria for different examples of cassava products

Group	Product	Main acceptance criteria	Reference
Non-fermented products made in a single step process	Boiled cassava	Not hard; soft (ease of cooking)	Hongbété et al., 2011
		Soft; mealy or friable	Hongbété et al., 2011; Favaro et al., 2008
	Fried cassava	Crispy; friable	Grizotto and De Menezes, 2002
		High dry matter; oil content; good colour	Vitrac et al., 2001
Non-fermented products made into industrial products: dried raw cassava products	Dried chips	Shape; high dry matter content	Falade and Akingbala, 2010
	Pellets	Regular in shape, high dry matter content	Falade and Akingbala, 2010

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	Starch	Minimal cassava starch content of 95%; white in colour; bland in taste, not sour; low in cyanide (<10mg/Kg); has particle size <0.12mm; odourless; free of foreign matter; free of mould, with low microbial count; has a maximum moisture content of 12%; not fermented (pH >5)	ARS:846, 2012; Eke et al., 2010

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	HQCF	White in colour; bland in taste, not sour; low in cyanide (<10mg/Kg); has particle size <0.25mm; odourless; free of foreign matter; free of mould, with low microbial count; has a moisture content of 10-12%; not fermented (pH >5.5)	ARS:840, 2012
Products fermented by (water)	Fufu (paste)	High dry matter	Etudaiye et al., 2009

submersion		Various homogeneous colours: off-white colour; creamy-white, grey or yellow.	Opare-Obisaw et al., 2004; Falade and Akingbala, 2010
		Slightly sticky; stretched like wheat flour dough and moulded neatly into balls	Opare-Obisaw et al., 2004

		Smooth texture (with no lumps); soft	Akingbala et al., 1991; Opare-Obisaw et al., 2004; Falade and Akingbala, 2010 Tomlins et al., 2007
		Bland smell and taste	Opare-Obisaw et al., 2004

		Typical fufu slightly sour taste and odour (increased with the length of fermentation)	Akingbala et al., 1991; Tomlins et al., 2007; Oyewole et al., 2004; Falade and Akingbala, 2010
	Lafun (paste)	Homogeneous; smooth; 'good' texture and taste; sticky; well cooked	Oyewole and Afolami, 2001
	Chikwangue	Typical smell and taste; elastic; sticky; slightly sour taste; size; shape	Adoua-Oyila et al., 1995

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Solid state fermented products	Agbelima	Cohesive; smooth; good taste; slightly sour; homogeneous colour (bright-white)	Dziedzoave, 1996; Dziedzoave et al., 1999; Dziedzoave et al., 2000
	Gari	High swelling index associated with better texture (increased with fermentation time)	Blanshard et al.,1994; Achinewhu et al., 1998; Oduro et al., 2000; Irtwange and Achimba, 2009; Owuamanam et al., 2010
		Homogeneous creamy/yellow colour	Oduro et al., 2000; Achinewhu et al., 1998

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		Particle size; degree of coarseness; low level of extraneous matter, appreciable level of crude fibre content,	Oduro et al., 2000; Blanshard et al.,1994; Achinewhu et al., 1998
		Slightly sour and flavoured taste (increased with fermentation time)	Oduro et al., 2000; Ray and Sivakumar 2009; Owuamanam et al., 2010
		Low moisture content	Oduro et al., 2000; Achinewhu et al., 1998

	Attieke	Homogenous granules (equal size); no extraneous particles; sweet; not too sour; aromatic and slight sour smell, high swelling index	Djeni et al., 2011

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Table 2. Some main quality traits for cassava (adapted from www.cropontology.org)

Type of analysis		Trait
Biochemical analyses	Macronutrients	Starch: amylose/amylopectin
		Fibres: neutral ; total ; lignocellulose
		Pectic compounds
		Ash
		Sugars
		Organic acids
	Nutritional factors (Micronutrients)	Carotenoids: total; trans and 9-cis beta carotene; zinc; iron
	Anti-nutritional factors	Cyanogenic compounds: linamarin ; lotaustralin ; free cyanides Phytates
Physical analyses	Instrumental texture	Stickiness; softness, elasticity; swelling power
	Dry matter	Dry matter content of the roots
	Product yield	Yield of gari; fufu; lafun / roots

Table 3. Proximate, vitamin and mineral composition of cassava roots and leaves

	Proximate composition (for 100g)	**Cassava roots**
	Food energy (kcal/(kJ))	110/(526)-149/(611)
	Dry matter (g)	30-40
Macronutrients	Protein (g)	0.3-3.5
	Lipid (g)	0.03-0.5
	Carbohydrate (g)	35-38
	Dietary fibre (g)	0.1-3.7
	Ash (g)	0.4-1.7
Vitamins	Thiamine (mg)	0.03-0.28
	Riboflavin (mg)	0.03-0.05
	Niacin (mg)	0.6-1.1
	Ascorbic acid (mg)	15-50
	Vitamin A (µg)	May-35
Minerals	Calcium (mg)	16-176
	Phosphorus (mg)	6-152

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	Iron (mg)	0.27-14.0
	Potassium (g)	0.25-0.27
	Magnesium (g)	0.03
	Copper (ppm)	2
	Zinc (ppm)	14
	Sodium (ppm)	76
	Manganese (ppm)	3

Source: Montagnac et al. 2009; USDA food composition cassava (2015)

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Table 4. Summary of the possible improved quality traits, genes associated, sensory perception and consumer acceptance

Quality Trait	**Example of gene**	**Sensory perception**	**Potential processor/consumer acceptance**
Higher Yield of product/root Higher dry matter content Higher starch content	Increase AGPase enzyme Conversion sugar to starch production	Less moist and more filling perception	More product for the same quantity of roots (farmer/processor adoption) Consumers like high dry matter root crops (moist cassava not liked)
Starch pasting viscosity characteristics	Genes related to pasting properties in several locations on the genome 15 QTL identified (Thanyasiriwat et al., 2013)	Texture	*e.g.* Gari: swelling index maximum *e.g.* Fufu: smooth; no lumps; mouldable and elastic
Increased Pectin content	Overexpressing PEST1 gene increased pectin methyl esterase (PME) production in potato -- dual role	Increased firmness (texture) in cooked potato (Pectin drives friability and cell-cell adhesion)	Firmer products for better acceptance or better softening of the roots
Higher Protein content	Expressing CaMV35S promoter -- increased protein and amino-acids content	Not known	Not known

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Higher carotenoid content	Overexpressing phytoene synthase (PSY) regulated by genes PSY2	Colour (yellow colour) and taste	Yellow colour acceptable and softer and sweeter taste acceptable to end-users
Higher Zinc content	Research in process	No change in sensory characteristics. Threshold?	No change in acceptance expected
Higher Iron content	Research in process	No change in sensory characteristics. Threshold?	No change in acceptance expected
Lower Cyanogenic content	Overexpression of hydroxynitrile lyase (can reduce acetone cyanohydrin content during processing)	Bitterness is generally linked to cyanogen potential (soluble sugars can however mask bitterness)	-Less bitter is better for the consumer -More flexibility for processing -But farmers like high cyanogenic varieties because better against pests and animals
Post-harvest Physiological Deterioration (PPD)	Reduce expression of genes for scopoletin that is linked to PPD in cassava	Improved appearance, smell and taste due to better shelf life	PPD significantly affect end-user acceptance and marketing of roots

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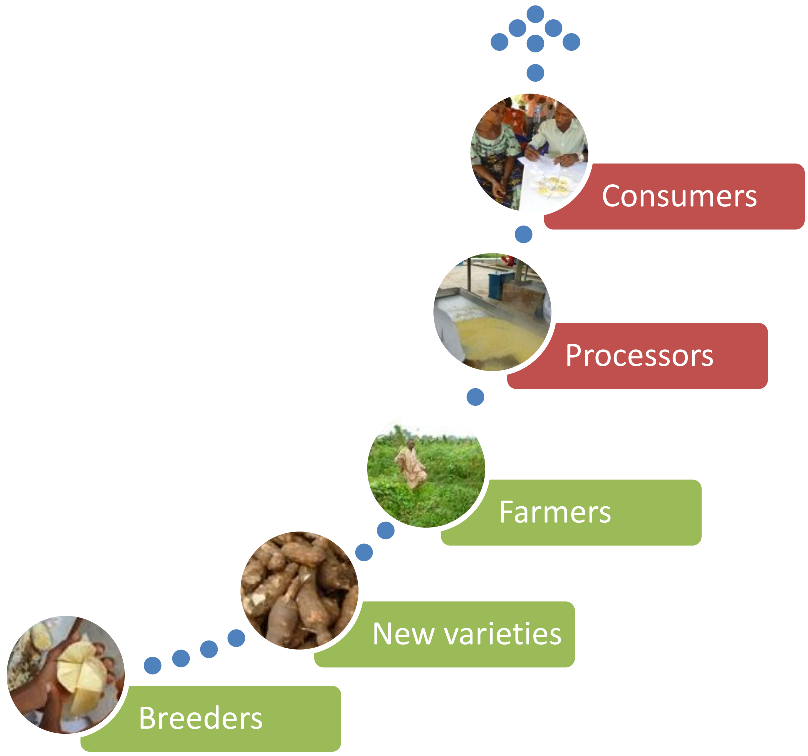

Figure 1. Simplified chart showing the process of development of improved or new cassava varieties: from the breeder to the consumer

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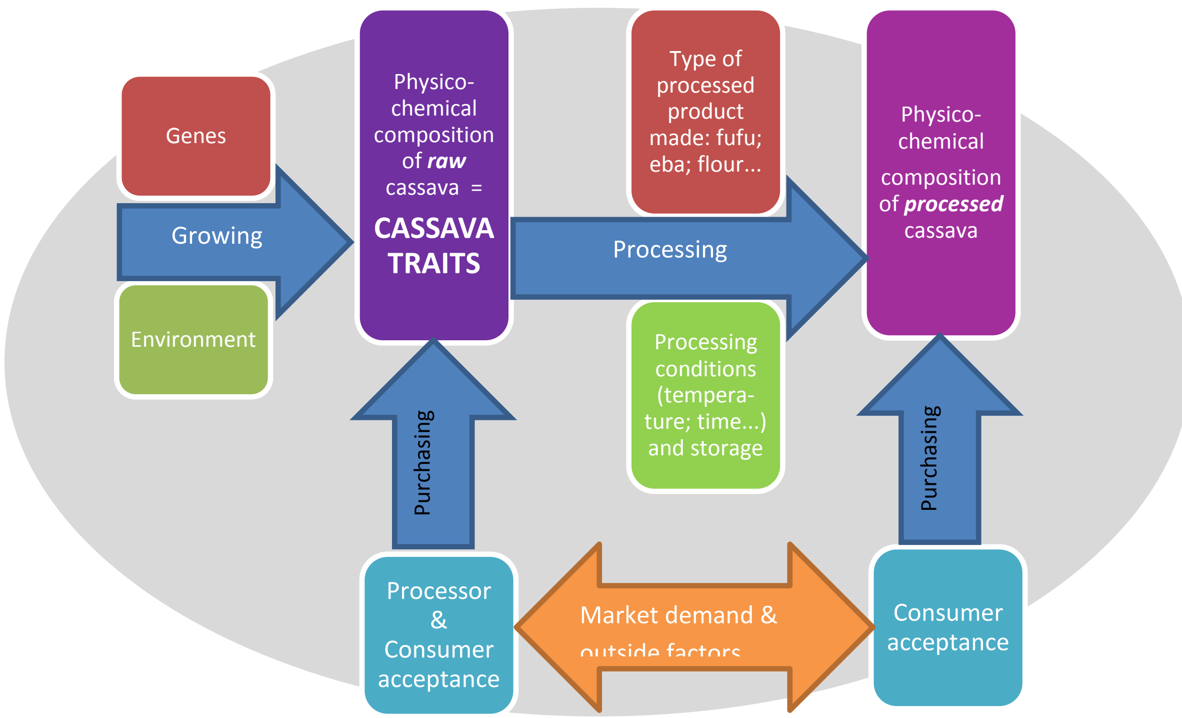
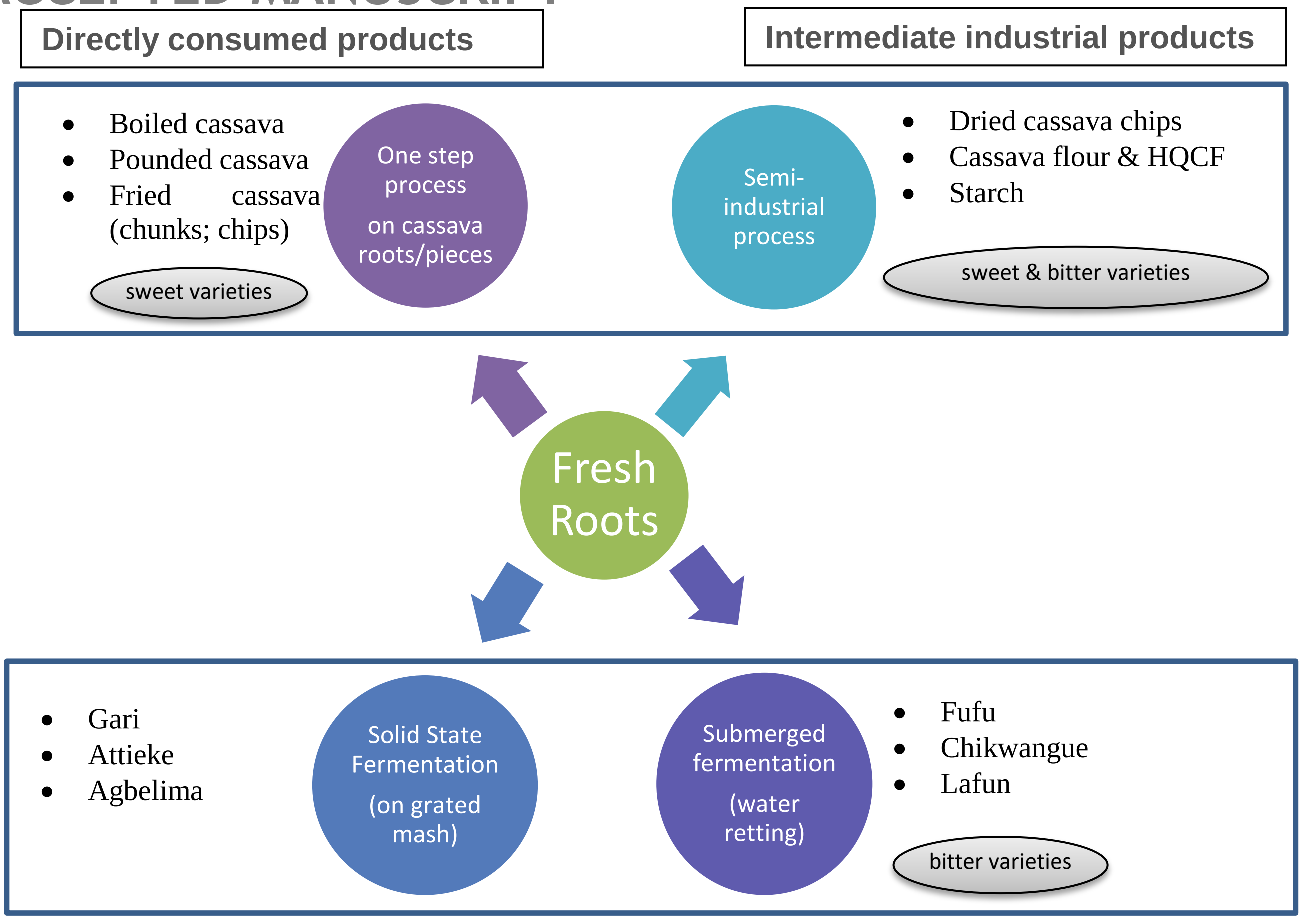


Figure 2. Schematic representation of relationships between cassava traits and end-user acceptance



Fermented cassava products ***(Multi-step process) Detoxification & taste development***

Figure 3. Schematised description of the different types of African cassava products

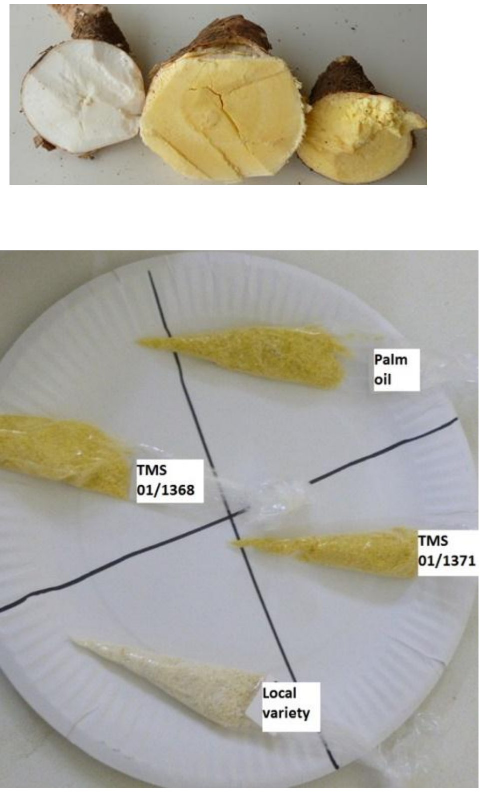


Figure 4. White (local) and yellow (biofortified) cassava roots (A) and gari made from white (local), white and palm oil and yellow (biofortified) cassava varieties TMS 01/1371 and 01/1368 (B). Source: Bechoff, A. Photo, Nigeria.

