Cassava bread in Nigeria: the potential of 'orphan crop' innovation for building more resilient food systems

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Abstract: Achieving global food security sustainably is a great challenge in the 21st century. This paper proposes that orphan crop innovation has the potential to help address this need. Using the case study of cassava bread in Nigeria, it demonstrates the barriers to and mechanisms for developing innovation systems for orphan crops. It finds that the goal-oriented search for cassava bread was successful, but the wider systemic weakness that its invention was supposed to address required further interventions. Furthermore, when the benefits of a specific product do not accrue directly to the end-users, but are felt further up the supply chain, it is difficult to incentivise the private sector to invest in these types of innovation because there is no clear target market. This requires collaboration and trust between public and private sector actors, which is especially important due to ethical concerns in bridging formal technological innovation with traditional knowledge systems.

Keywords: orphan crops; neglected and underutilised species; innovation; food security; cassava; Nigeria.

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1 Introduction: global food trends

Achieving the goal of global food security sustainably is one of the greatest challenges of the 21st century. With a current world population of 7 billion, expected to rise to 9 billion by 2050, global demand for food is increasing (Beddington et al., 2012; FAO et al., 2015). Food price spikes from 2008 have dramatically affected the affordability of food for much of the world's poor, halting the progress that had been made towards meeting the first MDG of halving hunger by 2015, and setting up a challenge to achieve the second sustainable development goal (SDG) of eradicating hunger. Added to this is a burgeoning crisis in how we use the food we do access: the food system is failing to meet the needs of 805 million chronically undernourished, 2 billion with micronutrient deficiencies and 500 million obese people (FAO et al., 2015; WHO, 2015). An ailing food system exacerbates problems in the health system with severe health implications not only arising from under-nutrition, but with obesity and being overweight being linked to 44% of the diabetes burden, 23% of the ischemic heart disease burden, and 7–41% of certain cancer burdens (WHO, 2015; Cordain et al., 2005). Compounding these trends is that with increasing affluence, diets are shifting dramatically towards a 'Western diet' of more animal, sugar and fat products to the exclusion of more traditional – and sometimes more sustainable – diets (Kastner et al., 2012). The current food system is not resilient – a focus on increased production has made it more environmentally unsustainable and susceptible to shocks like climate change, whilst lower prices and global trade has resulted in more than half of the world's population suffering from diet-related issues.

Associated with these unsustainable trends is a decrease in the amount of diversity in our diets. Currently 75% of the world's food needs are met by 12 plant and five animal species (FAO, 2004) and despite an estimated 12,000 edible plant species, currently nearly 60% of human calorific needs are met by the 'big three' crops: rice (*Oryza sativa*), maize (*Zea mays*) and wheat (*Triticum spp*) (FAO, 1999). Furthermore, whilst the rural poor depend mainly on biological resources for the majority of their needs, the poorest farming communities, especially in Africa, have benefitted little from high-yielding varieties (FAO, 1999; Wynberg et al., 2012). Added to the unequal status quo, the food system is also projected to face increasing environmental pressures as we start to exceed planetary boundaries (Rockström et al., 2009). Climate change is one such environmental change that could have detrimental effects on the food system's ability to provide food security to a growing population (IPCC WG II, 2014). However, when it comes to measuring the projected impacts of climate change on crop production, the scientific community has focussed on the three main staple crops of maize, wheat and rice to the exclusion of other 'orphan crops' (e.g. Easterling et al., 2007). Although more studies are now being conducted on important food crops like sorghum, millet and cassava (e.g., Schlenker and Lobell, 2010; Lobell et al., 2008; Jarvis et al., 2008), there needs to be fundamental shift in recognising that underutilised crop species have a critical role to play in achieving food security both now and in the future (See Galluzzi and Noriega, 2014).

Given these global food challenges, it is an opportune time at which to discuss new ways of addressing these problems by reorienting food innovation systems towards sustainability and equality. The legacy of the green revolution is an innovation system for food security that emphasises improving agriculture by increasing crop yields through improved inputs: from seeds to machinery and irrigation (Ingram, 2011; Pingali, 2012). Although these innovations have undoubtedly improved food security in terms of increasing the total calories grown globally, they have left out the rest of the food value chain – where concerns over access and nutrition are addressed.

One of the critical areas for innovation in the food system therefore centres on behaviour change and people's taste preferences – both in the developed and developing world. Current food consumption trends in the developed world and increasingly in emerging economies are unsustainable (Godfray et al., 2010), but as people become more affluent, price indicators alone are not going to succeed in incentivising people to eat more sustainably. On the food consumption side, companies have invested heavily in the creation of novel foods that meet demands for tasty, convenient meals, but that often run counter to cultural traditions around food and the high sugar and fat contents of these foods have been shown to have severe negative health consequences (Nestle, 2007; Pollan, 2008). The excess nutritional load that is wasted in this highly processed, industrial 'cheap food' system has repercussions where people's food needs are not being met (Pereira, 2014). It is thus high time for food innovation systems that take a food-security centric view that measures innovation in terms of health and sustainability benefits, not just the bottom line. This paper hopes to contribute is to our understanding of how to develop innovative solutions for achieving a sustainable food system that meets the world's food security needs, using the lens of orphan crops.

In this paper, it is proposed that developing innovation systems for orphan crops- understood here as those crops that are not the 'big three' global staples (rice, maize wheat) or 'cash crops' (e.g. soybean, sugar cane, oil seeds, cotton) – could help to meet food security objectives in an uncertain future. Considering the threat that climate change poses to the food system (IPCC WG II, 2014), strategic adaptation would invest research into those crops that have a significant role to play in meeting food security needs whilst maintaining local food customs. This would prioritise those crops whose value chains are not controlled by a small number of transnational corporations, as is the case for the vertical integration of most elements of the maize, wheat and rice value chains (Patel, 2007; Meijerink and Danse, 2009).

After a brief discussion on the potential of orphan crops in the next section, this paper provides a case study example of cassava (*Manihot esculenta*) in Nigeria to illustrate the complexities of doing orphan crop innovation that can achieve the goal of food security and social welfare within environmental limits. It provides an interesting contribution by focusing not only on innovation beyond the farm gate (i.e., not on agricultural production), but highlights innovation concerns across value chains in developing countries. It also illustrates the importance of engaging across public-private-civil society sectors in moving orphan crops up the investment agenda and dealing with socio-cultural barriers to innovation.

2 Opportunities from the diversity of orphan crops

What we eat is as much a cultural and social practice as it is one of survival and so it will require a concerted innovation effort in the food system to develop food products that not only meet sustainability requirements, but that also meet people's needs regarding taste, social acceptability and nutrition. This paper argues that an increased focus on innovation for 'orphan crops' provides a step in the right direction because they build resilience in the food system through a triple-win of diversity: agro-biodiversity, farming system diversity and dietary diversity.

Agro-biodiversity is a subset of biodiversity that consists of the plants, animals and micro-organisms that are used directly or indirectly for food, fodder, fibre, fuel and pharmaceuticals (FAO, 1999). Over the past century, as farmers have looked to increase yields through a variety of agricultural practices, the species diversity on which agriculture is based has been severely eroded – to the extent that an estimated 75% of plant genetic diversity has been lost since the 1900s as farmers replace local varieties and landraces with high-yielding varieties, often from a different country or region (FAO, 2004). Although the need to conserve the genetic diversity of these plants and their varieties has been recognised – there are Gene Banks dedicated solely to preserving plant genetic material such as the Svalbard Global Seed Vault – this does not satisfy one of the key requirements for maintaining biodiversity; that *ecosystems* require functional redundancy in order to be resilient to shocks (Berkes et al., 2003; Folke, 2006). Enhancing the diversity of crops that we grow and consume will positively impact the biodiversity of agricultural systems, enhancing their ability to absorb shocks such as climate change. The argument for increasing biodiversity is not merely about retaining diverse genetic material that may have unrecognised potential, but that ecosystems, including agricultural systems, become more resilient when functionally diverse, and furthermore have the potential to provide a variety of other services such as carbon sequestration or water purification.

Linked to increasing the diversity of what is grown is an increased diversity in what is available for consumption. As mentioned earlier, global dietary diversity has eroded over the past century. The concentration of the food system on three staple crops does not leave space for many other species that have the potential to meet nutritional needs, particularly under a changing global environment. It also results in only the more affluent being able to afford a healthier, more diverse diet that consists of a greater variety of grains, fruits and vegetables (James et al., 1997). Investing in innovation that includes more diversity in our diet could thus have positive health outcomes for the poorest.

As well as the ecological and health arguments, there is also a livelihoods-related argument for increasing the diversity in our diet. This is largely because 90% of poor smallholders' crops come from seeds and planting material they've selected themselves (FAO, 1999). Studies conducted on traditional farmers in South Africa have shown that along with being active plant breeders conserving traditional varieties, these farmers also have many insights into ecologically sound farming practices such as natural pest and disease control, soil preparation and water management that have been passed down orally for generations (Wynberg et al., 2012). Women in particular often hold much of the knowledge about plant varieties, seed traits and uses of non-staple plants as well as knowledge around small livestock breeding and other agricultural practices associated with indigenous varieties (FAO, 1999; Wynberg et al., 2012; Hosken, 2015). With the former UN Special Rapporteur calling for an increased interest in agro-ecology (De Schutter, 2010), orphan crops provide the lens for exploring these diverse methods of agricultural production.

The rest of the paper provides a case study example of where orphan crop innovation is starting to take place. With regards to the use of cassava as an example in this paper, recent studies from the biotechnology and plant breeding perspective still regard cassava as an underutilised or neglected crop (Jain and Gupta, 2013; Galluzzi and Noriega, 2014). Although due to its widespread use as a staple crop across much of Africa and Latin

America, others would argue against this assertion. Whilst it is an important discussion to be had regarding the categories into which we place certain crop species and varieties, the lessons that can be learned from this case study are extremely relevant for building up an innovation system for a diversity of crop species.

3 Methods

The research for the project consisted of a combination of primary and secondary sources. An extensive review of the literature on cassava in Africa was conducted and expert advice from researchers was sought in order to determine the state of the science on cassava in Nigeria. To get a sense of the institutional history of cassava processing in Nigeria and the perception of cassava bread in particular, a review of media sources in Nigeria was also done- this included looking at newspaper articles, comment pieces and youtube video clips. Fieldwork was also conducted in Nigeria over a 10-day period. This consisted of semi-structured interviews with two experts in the National Ministry of Agriculture in Abuja and the Lagos Commissioner of Agriculture. As well as the information gathered in the interviews, these meetings also resulted in access to government documents on the action agenda for cassava (FMANR, 2012). A three-day workshop was held in conjunction with the Governor's office in Osun State that included members of the cassava farmers' union and experts from the International Institute of Tropical Agriculture (IITA). The first two days of the workshop took place in Osogbo and included a day fieldtrip to farms producing cassava, to rural processing markets as well as to a closed-down cassava flour mill. The second day of the workshop took place in Ibadan at the IITA where scientists who had been involved in the original work on cassava from the 1980s were present.

The project was a case study for the innovation and access to technologies for sustainable development project at Harvard Kennedy School's Sustainability Science program (Anadon et al., 2016). It uses the conceptual framework of this project, set out by Diaz Anadon et al. (2014), to explain the innovation cycle.

4 Cassava bread in Nigeria

4.1 Why cassava?

Since its debut in the late 1600s on Portuguese trade ships from Brazil into Nigeria, cassava has become an important crop that accounts for between 30–50% of all calories consumed in Southern and Central Nigeria (FMANR, 2012). It is produced predominantly by small farmers with 1–5 ha of land, intercropped with yams, maize, or legumes in the rainforest and savannah areas of Southern, Central, and recently Northern Nigeria and processed locally by rural women (See Figure 1). Nigeria is now the largest producer of cassava in the world producing 52.4 million metric tons in 2011, almost double the second highest producer, Brazil, but it is not even amongst the top 20 countries exporting processed cassava; Thailand is currently the largest exporter (FAOSTAT, 2013). Reasons include Nigeria's cassava sector having low productivity, leading to high costs per unit production, and an inability of Nigerian cassava products to compete with imported substitutes resulting in a lack of demand for cassava by industrial users who prefer to import raw materials (FMANR, 2012).

Figure 1 Rural women processing cassava in a village market, Osun State (see online version for colours)

Cassava has characteristics that make it potentially very useful for a transformation agenda in the food system. It is uniquely adapted to conditions of low soil fertility, high acidity and drought and is expected to be resilient to projected climate change impacts in sub-Saharan Africa (FAO, 2008; Lobell et al., 2008; Jarvis et al., 2012). In addition, it has many other benefits including its long harvesting period, an ability to remain stored underground for long periods of time, its appropriateness for mixed cropping systems and its low labour intensity comparable to other cereal crops (Nweke et al., 2001; FAO, 2008). Due to their high starch content, cassava tubers provide a major source of calories well as phosphorous and calcium, whilst the leaves, which are often included in African cuisines, are a cheap and rich source of protein, iron, vitamins A, B1, B2 and C (Nweke et al., 2001; Ecocrop, 2012). However, the tubers themselves are deficient in protein and other micronutrients including Iron, Zinc and Vitamins A and E (Sayre et al., 2011).

Cassava can also be made into a variety of by-products, not only food, feed and fuel, but also industrial products like glue (FAO, 2008). However, the plant does require specific processing in order to reduce its toxins (like HCN acid) and to improve its taste (FAO, 2008). Unfortunately, cassava roots are more perishable than other major temperate or tropical root crops; they deteriorate extremely rapidly after harvest due to physiological and pathological deterioration and so cannot be satisfactorily stored for more than a few days (Wenham, 1995). It therefore it needs to be processed into more stable products like cake, chips, flour and pellets almost immediately after harvest (FAO, 2008). Thus, cassava offers as many challenges to scaling up commercialisation of the product as it does opportunities for addressing issues of food security in Africa.

Processed cassava is a reliable and convenient source of food for tens of millions of rural and urban dwellers in Nigeria and it is estimated that 90% of cassava production is processed into food (Nweke et al., 2001; Phillips et al., 2006). Although the bulk of the production is still for home consumption and traditional food products like *garri* and *fufu*, there has been an increase in processing for industrial end-user markets such as flour mills and bakeries thanks largely to government supported initiatives to increase the value added to cassava products (Kleih et al., 2008). According to the FMANR (2012), in Nigeria the principal users of cassava (about 70% annually), are village-level *garri* processors that require limited quantities of fresh roots per day whereas large processing plants in Nigeria that need larger quantities are faced with a shortage due to the low starch content of roots from old plants (> 15 months old), high transaction costs (of collecting small amounts of cassava over a large area with bad roads), and adversarial relationships between the producer and processor. This results in the challenge set out in this case study; that of processing plants operating below capacity while a significant percentage of farmers are left with unsold harvest.

4.2 High quality cassava flour (HQCF) and cassava bread

As a means of addressing these challenges, Nigeria's former President Goodluck Jonathan established the cassava transformation action. The plan aims to drive development in the cassava sector by capitalising on opportunities that exist in the industrial and export sectors for cassava through value addition. In particular, considerable effort is to be expended on developing novel products that have the potential to increase the overall profitability of the value-added chain (FMNAR, 2012). The most promising market to meet these objectives is that of HQCF as a replacement for wheat flour in the bakery sector (Adebayo, 2010). The main reasons for focusing on HQCF are that many farmers already know how to create the basic raw material for HQCF (grated cassava), value can be added at the rural household level by processing of the intermediate product (cassava grits or wet paste), thereby increasing incomes for farmers; the requirements for capital investment is lower and less environmental damage is caused than by starch manufacture (Adebayo, 2010). Estimates indicate a potential demand of 250,000 ton/year for HQCF, primarily from 10% replacement in bread flour and for use in other industries; a demand equivalent to 1.15 million tons of fresh roots (FMANR, 2012).

The use of cassava flour in bread is also highly strategic. Urbanisation, lifestyle changes and increased affordability have increased the consumption of bread in Nigeria, however, the wheat from which to make bread flour does not grow well in Nigeria's tropical climate and so the country currently imports wheat worth N635 billion (approximately 4.2 billion USD) annually, depleting its foreign reserves, in order to meet this demand (Ohimain, 2014). In response to this, the 'cassava bread development policy' was developed by then President Jonathan and his minister of agriculture, Dr. Adesina. This is a type of import substitution plan to halt Nigeria's reliance on imported wheat whilst simultaneously building a domestic market for cassava products in the urban centres.

This case study analyses the cassava bread innovation system in Nigeria with a focus on identifying socio-technical mechanisms that underlie the flow of knowledge and technologies in the innovation system. The case identifies potential points of intervention in the cassava bread innovation system to improve the ability of this technology to contribute to sustainable development in Nigeria and concludes with lessons about developing innovation systems for orphan crops.

4.3 The cassava bread innovation timeline

4.3.1 1980s

Systemic interventions in the Nigerian cassava sector began in the early 1980s with the aim of transforming the crop from a rural subsistence crop to a cash crop and urban food staple (Nweke et al., 2001). Early results included the development and introduction of high yielding, early bulking varieties resistant to the cassava mosaic disease and cassava bacterial blight, bred by the IITA, and the establishment of small-scale processing facilities (Nweke et al., 2001). 'The cassava transformation' as the rapid increase in production and marketing has been termed transformed the crop from a rural subsistence crop to an urban food staple (Nweke et al., 2001). As part of this initiative, researchers at the IITA together with Nigeria's Federal Institute of Industrial Research (FIIRO) developed HQCF. The success of HQCF then led to research on the different combinations of cassava/wheat composite flour to make a loaf of bread (Ajibola, 1988). However, in the 1990s the cassava agenda in Nigeria was largely neglected under the military dictatorship.

4.3.2 2003–2007

In 2003, the second wave of cassava innovation began in Nigeria. Driven by President Obesanjo, the Presidential initiative on cassava sought to make cassava a commodity crop and foreign exchange earner by transforming its role in the economy beyond that of a 'traditional' food crop and into a staple that could compete with wheat, maize and rice. In addition to increasing the total amount of cassava being produced in the country, this initiative focussed on improving cassava-based food products. There was now an institutional incentive to use the research from the 1980s to bring a product to market. Researchers using the composite flour had shown that mechanical leavening rather than bulk fermentation for the ripening of the dough and a blend of 60% wheat flour, 30% cassava starch, and 10% soybean flour, produced a bread of good quality almost equal to the incumbent wheat-flour bread in volume, appearance and taste (Taiwo et al., 2002). Joint research had finally succeeded in using HQCF as a viable partial substitute for wheat flour in baking bread. However, the acceptability of cassava as a substitute by consumers was still problematic; cassava-based bread was still considered inferior to wheat-based bread and the use of cassava in a composite flour needed improvement (Liverpool et al., 2009). When President Yar'Adua succeeded Obesanjo, cassava was once again off the government's agenda, but joint research continued to take place between the IITA and FIIRO.

4.3.3 2011–2014

By the time that President Jonathan officially took office in 2011 a 20% HQCF loaf had been developed that met standards of colour, crust, taste, texture and aroma. However, there had been very little commercial prospects for the technology due to a variety of cultural and institutional barriers (Ukwuru and Egbonu, 2013). These included the fact that millers were only willing to mix composite flour containing 5% cassava flour and because bakers claimed that the loaves made from any higher percentage of cassava flour did not meet customers' quality standards (FMANR, 2012). This complaint was largely due to both flours being of insufficient quality and a lack of know-how rather than a problem with the technology itself. The emphasis of the innovation system therefore had to move from an emphasis on the ‘invention’ stage to focus on the ‘production’ and ‘sustained use’ stages of the innovation system.

Figure 2 Cassava bread and other baked goods available from stores in Abuja (see online version for colours)

During the initial cassava bread development phases, there had been little emphasis on the marketing of cassava bread, but this changed when the cassava transformation agenda was initiated in 2011. A fundamental aspect of the agenda was in essence an import substitution policy to halt Nigeria’s reliance on imported wheat: the cassava Bread Development Policy. In May 2012, this bill making it compulsory for all bread to contain between 10–40% cassava flour was brought to the House of Representatives, but it was met with stern opposition. The Minister of Agriculture said that it would save Nigeria approximately $252 million in wheat imports whilst building a domestic industry, but opposition to the bill came from the wheat importers lobby as well as the Association of Master Bakers, Confectioners and Caterers who said that they did not have the means or technology to make the bread. Added to this were controversies over cassava from a health perspective, with its anti-nutritional properties being touted together with an argument that it was unsafe for diabetics of which Nigeria has a high percentage in the population.

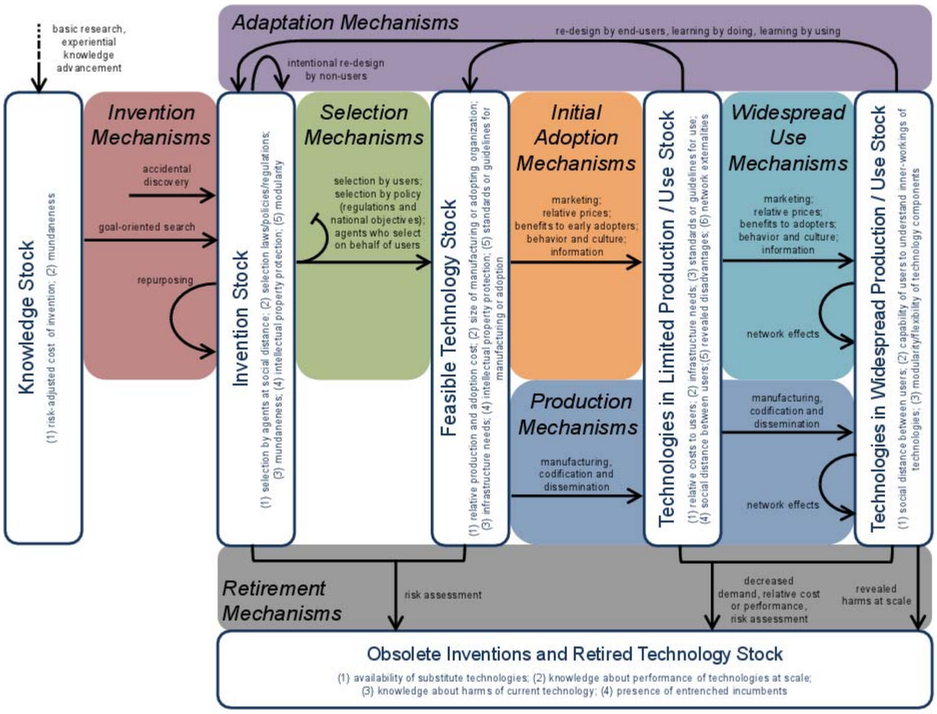
The bill did not pass, but in July 2012 the Federal Executive Council (FEC) passed fiscal policies aimed at promoting the adoption of cassava bread. These include a 65% levy on the importation of wheat flour, 15% on wheat grain that would be paid with the 35% duty on the commodity. Cassava flour imports were banned and there was duty free import of equipment for processing HQCF. Bakeries with 40% HQCF inclusion were also to receive a 12% corporate tax rebate. Part of the funds generated from this initiative would go towards a cassava bread development fund to build capacity in the agricultural sector through expertise in producing, processing and exporting cassava. Along with this, the tariff on an enzyme critical to the processes of making cassava bread would be removed.

The end result of these manoeuvres has been the successful development of a loaf of bread made with 20% HQCF that looks and tastes like a 100% wheat-flour loaf, which can be bought in some stores in Lagos and Abuja (see Figure 2).

5 Case study analysis at each stage of the innovation system

The case study of cassava bread in Nigeria portrays an interesting combination of innovation in terms of both the physical technology and knowledge as well as the creation of social or institutional innovations to enable the technology to advance through the various stages. This case is analysed by applying a conceptual framework of an innovation system. This model was developed by a team of researchers convened by Harvard University (of which the author was a part) to study a broad set of innovation case studies. The framework utilises system dynamics concepts of stocks (knowledge, inventions, feasible technologies, technologies in limited production/use, technologies in widespread production/use, and obsolete or retired technologies) and flows (invention, selection, initial adoption, production, widespread use, adaptation, and retirement) to describe the generalisable processes that help understand how technologies evolve and where barriers might arise (see Figure 3). The figure is explained in more detail in Anadon et al. (2014). Using this framework, the main barriers of each stage if the innovation system are identified together with the key mechanisms for overcoming these barriers.

Figure 3 Conceptual model of the innovation system (see online version for colours)



Source: Diaz Anadon et al. (2014, p.23);
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5.1 Invention stage

The initial barrier to the technology was a *knowledge gap* as to how to make use of cassava in staple food products like bread, beyond 'traditional' uses of the crop in foods such as garri or fufu. From the 1980s as part of government-led strategy, research had been done by the IITA together with Nigeria's FIIRO to develop a technology that allowed for cassava to be made into a HQCF that could then be combined with wheat flour to make cassava bread. The mechanism employed to overcome this barrier can be classified as a *goal-oriented search* for a means to create a value-added cassava product for the domestic Nigerian market.

5.2 Filtering stage

Towards the end of 2011, President Jonathan presented the bread to the FEC promising that it would be the only bread that he ate while in office. Hence, there was direct selection by the Nigerian executive government for the technology because it was seen to fulfil multiple government objectives. The mechanisms at the filtering stage were driven by a combination of linking cassava bread with a rhetoric of *national pride* as well as *economic incentives*, however it met with resistance.

These barriers included the *regulatory structure* through which the government attempted to push the bread into the market, *knowledge gaps* about the technology by some members of the House of Representatives and the Association of Master Bakers, Confectioners and Caterers and a *collective action problem* of bringing all the various stakeholders onto the same page. Finally, there were *vested interests* from the wheat import lobby that would have suffered the most from the introduction of the technology and the legislation enabling its production. This group strongly opposed the retirement of the incumbent technology and actively resisted policies to promote cassava bread.

The government enacted *fiscal policies* aimed at promoting the adoption of cassava bread in order to overcome the regulatory structure barrier. Some barriers to the selection process were overcome through the mechanisms of *regulation*, however, the lack of consensus-building meant that there were still barriers to the initial adoption of the technology as many of the barriers, including the *vested interests*, the *knowledge gaps* and the *collective action problem* remained.

5.3 Production stage

There are two main barriers to production of cassava bread. The first lies in *supply chain weaknesses*, and in particular, the availability of HQCF of sufficient quality to be included by millers into the flour that they sell to bakers. The second barrier is a lack of consensus as to what percentage of HQCF is to be combined with wheat flour, which is driven by *divergent interests*. The latest agreement is that from the beginning of 2013 there will be an increase in the percentage of HQCF in composite flour up to 10%. Up until 10% cassava flour inclusion, the composite bread can be produced without the need of additives or improvers, however baking bread at the 40% inclusion rate that the government is advocating, requires improvers such as enzymes, chemicals, hydrocolloids and gums, emulsifiers, lipids and proteins – this means retrofitting of machinery, which can be expensive (Ohimain, 2014). This is another *financial barrier* to the production of the final technology.

There was a chicken and egg situation concerning the cassava value chain in Nigeria: the millers argued that it was necessary to agree on and regulate the percentage of HQCF in flour and to train bakers in how to bake cassava bread so as to create demand for cassava flour. The bakers and retailers argued that the inadequate processing capacity in Nigeria was the reason why end users had lost interest in sourcing their raw materials from the cassava sector and that this needed to be rectified before agreement on standards could be achieved. The importance of transforming the whole value chain was therefore emphasised – it was impossible to intervene at just one end of the value chain.

There were also *supply chain constraints* for adding value to cassava. These include the low flour yield of current varieties, the high cost of raw materials due to the low average yield per hectare on farmers' field, 8–11 t/ha, the old age of roots supplied from farmers, the dispersed nature of farms and poor road infrastructure that increases the *transaction costs* for supply of raw materials to HQCF processors (FMANR, 2012). *Low productivity* is in turn due to poor access and late supply of inputs, and lack of access to credit by farmers. On the processing side, there are quality issues with HQCF from SMEs; when HQCF is used as substitute in wheat flour quality specifications and compliance standards are high and requires an in-house laboratory to ensure each batch going to the flour mills meet the required standards (FMANR, 2012). Another barrier is the lack of suitable mechanical peelers by SMEs that increases the *cost of production*.

The lack of processing capacity and increasing the production of cassava in the country has resulted in direct *government-led intervention* to overcome the barriers listed above. The Ministry of Agriculture and Rural Development has a cassava team that "will aggressively pursue establishment of government sponsored but private sector run processing plants; it will also work with experienced international and local investors, via *joint ventures* and *partnerships*, to pursue opportunities in the HCQF value chains in staple crop processing zones (SCPZ) with high levels of demand and commercial production" [FMANR, (2012), p.24]. A key component strategy of the Agricultural Transformation Agenda is attracting private sector agribusinesses to set up processing plants in zones with high food production, or SCPZ Zones (Interview Ministry of Agriculture, 2013). The government aims to encourage investment in SCPZ by putting in place "appropriate *fiscal, investment and infrastructure policies*, including tax breaks on import of agricultural processing equipment, tax holidays for processors who re-locate to the SCPZ; supportive infrastructure, especially complimentary investment in roads, logistics, storage facilities and power" [FMANR, (2012), p.25]. A cassava trade and marketing development corporation (CTMDC) run by the private sector will aim to build market institutions around farmers (Technoserve, 2013).

5.4 Initial adoption stage

In this section, initial adoption will be considered as adoption by bakers, but reference to adoption and acceptance by the public at large will also be mentioned. The main barriers to overcome in facilitating cassava bread's entry into the markets was one of *path dependency on the incumbent*, 100% wheat bread, as well as a *collective action problem* of co-ordinating the interests of the millers, bakers and retailers. For initial adoption, the focus will be on getting industrial bakers on board, which also requires a guaranteed consumer market for the product. Smaller scale bakeries (that produce the majority of bread consumed in Nigeria) will be discussed under the 'sustained use' stage of the innovation system.

The success of getting industrial bakers to adopt the bread was largely through the mechanism of the *financial incentives and regulations* mentioned previously – including an incentive for higher inclusion with a 12% corporate tax rebate for bakeries with 40% cassava flour inclusion. The regulations, including high duties on wheat imports have resulted in a 3.06% saving in producing cassava bread (with 10% cassava flour) compared to 100% wheat bread [Kleih et al., (2008), p.37].

Finally, the federal government has approached the private sector to help with a social marketing campaign for the bread that draws on national pride in the product. This mechanism is aimed at increasing awareness about its properties and to help in creating a viable market for the product.

> "What we want to do now is to first of all speak to the conscience of the people, promote the consumption of the product more… The social marketing aspect is the key now, it's what we want to embark upon- when it is popular, when it is widely accepted, then we can go along together, but if it is not widely accepted we will still have a lot of struggle in the national assembly because there will be public hearings... and we don't want them to throw it out, we need to do a lot of social marketing. Speaking and reaching to the people to be patriotic enough to look at the advantages in terms of job creation, in terms of foreign exchange, and so on and so forth. This is what we intend to do." (Interview Ministry of Agriculture, 2013)

5.5 Widespread use stage

With some industrial bakers having adopted the technology, the barriers to sustained production of cassava bread include a *capacity deficit* of small-scale bakers to take up the technology as well as a reluctance to invest in switching to this new technology without guaranteed customers as there had previously been concerns about the quality of the product. Thus, *cultural barriers* regarding what bread should look and taste like are important factors to consider under widespread use. Finally, there is also a knowledge gap amongst bakers as to how to bake the bread. There are 450,000 master bakers in Nigeria and they bake 95% of bread eaten in the country therefore it is of key importance that these smaller bakers are able to adopt the technology (FMANR, 2012).

The barriers identified above were highlighted by the Chairman of the Bakers Association of Ondo State at a discussion at the agricultural development program (ADP) premises in Akure (Kleih et al., 2008). The Chairman stated that there had been issues in the past with the inclusion of cassava or maize flour in wheat flour as "the bread was not good to eat with tea" [Kleih et al., (2008), p.26]. The importance of the exact volume and shape of bread to consumers had already been previously highlighted by flour millers. He stressed that for the time being, positive demonstration of the technology was more important than financial benefits as the latter had already been demonstrated.

The Federal Ministry of Agriculture responded with a variety of mechanisms to overcome these barriers. The Ministry drew up a program to train Master Bakers and provide them with 'starter packs'. *Training workshops* have been held for master bakers from Ekiti and Delta States and training continues in the remaining 34 States. Trained Master bakers are each given starter packs of one 50 kg bag of composite flour (20% HQCF, 80% wheat flour) and one kilogram enzyme improvers to enable them to start producing cassava bread. This was being made possible through a *grant* of $650,000 from the gates foundation. As of March 2013, 385 master bakers had already been trained and provided with a 'starter pack.' In combination with the other projects aimed at increasing cassava production and processing into HQCF, this will hopefully address the *supply chain weaknesses* and lower the *costs of adoption* through lower prices for HQCF compared to wheat flour. However, cassava bread is currently being promoted through *economic and other fiscal incentives* at the federal level, but if these were to be discontinued, it is unknown whether it would be able to sustain its market in the face of 100% wheat flour products, especially if the price of wheat on the international market were to fall. Hence, the government has now reached out to the private sector, and in particular, large-scale food processors and retailers, to join in a *social marketing campaign* to promote cassava bread.

5.6 Adaptation stage

Cassava bread has already undergone substantial adaptation since it was first researched in the late 1980s as various concerns regarding its taste, texture, shape and ability to rise were addressed. The different percentage levels of HQCF included in the bread can also be classified as adaptation and bakers have shown their willingness to experiment with different levels of HQCF, provided they know its gluten levels. Furthermore, the technology is not limited to cassava bread; indeed, it is almost easier to experiment with other baked goods because customers do not require them to conform to cultural standards in quite the same way as they do bread, which is a staple food. Other confectionaries, such as doughnuts, meat-pies, sausage rolls as well as croissants and cake have also been developed from the composite flour and some are available on the market (See Figure 2). This is an important issue to highlight because it gets to the point of needing a customer base to buy the new technology. As a new staple, bread is associated with specific requirements, whereas these other baked goods can be more experimental, reaching a smaller consumer base that has the potential to grow substantially once the products become more widely acceptable. Although up to now, the products that have been developed have high sugar, fat and salt contents, the potential for healthier product innovation with HQCF remains important. The private sector has recognised potential in the market for other baked goods made from HQCF and there has been a much quicker increase in uptake of these baked goods than there has been of cassava bread even though there has been no direct government push to market these products (Interview Ministry of Agriculture, 2013).

5.7 Retirement stage

A discussion of retirement of cassava bread is not yet relevant. However, it is feasible to suppose that it would be displaced if an alternative, perhaps cheaper or more nutritious food were to be developed. Perhaps the more important questions involving the retirement stage of the innovation framework address the barriers to retirement of the incumbent technology 100% wheat flour bread. The major barriers to retirement of the incumbent to make room for cassava bread include vested interests, *path dependency* and *technical capacity*.

6 Lessons for orphan crop innovation more broadly

The case of cassava bread study provides some key insights into the challenges facing orphan crop innovation more broadly. The biggest initial challenge was first of all to address weaknesses in the supply chain. In the case of cassava in Nigeria, these were symptomatic of sub-Saharan African agriculture: low yields, bad roads making transport expensive, few processing facilities despite growing demand for food products (Juma, 2011). Cassava bread technology was therefore more an enabling means to an end- that of developing the cassava value chain- than it was an end in and of itself. This meant that the market for cassava bread needed to be created, to the extent that much investment is now going towards 'social marketing' campaigns to help create demand for cassava bread. One can readily assume that a similar challenge would be faced by other orphan crops in the case of top-down development of a new food product. The lesson to be learnt by the relative success of other baked goods with cassava is that is that by pushing an alternative to a staple technology (in this case bread) to create large-scale demand is substantially more difficult than just introducing another product into the market. This is an important consideration for innovation in all orphan crops attempting to replace or substitute an existing staple food crop.

Since cassava bread is fulfilling a need indirectly- it was not developed for its consumer market, but rather to address problems further up the supply chain- government intervention was a critical component of the innovation system as there were no direct benefits for initial investment from the private sector. The 'public good' of rural development and job creation is seen as the purview of governments and yet they are rarely able to intervene directly in the market to stimulate demand, unless through public procurement schemes. Demand for the innovative product or process is a critical component of successful innovation. This was the paradox facing cassava bread – the technology that the innovation system produced was developed not to meet the needs of its consumers (who are happy with wheat bread), but to meet the needs of those further up the supply chain, like smallholder farmers, as well as to increase the country's balance of trade by importing less wheat flour. Unfortunately, it is often those further up the supply chain, small-scale farmers or processors (often women) that are not the direct consumers of new products (because they have very little purchasing power themselves), who have most to win or lose in the success of innovations for sustainable development. In the cassava bread case, there was an eventual realisation under Jonathan's government that after the lack of sustainable success achieved under the Obesanjo administration, bringing the private sector on board was vital to ensure the sustainability of the initiative (Interview Ministry of Agriculture, 2013).

The new emphasis on collaboration with the private sector and a focus on 'social marketing' may indeed provide a recipe of success for cassava bread. However, there is very little trust between the various actors that needed to work together to see this project fulfilled and these relationships are tenuous in an unstable political climate. The real results will only be measurable in a few years' time when it will be possible to analyse how many more farmers have access to markets for their cassava crops, whether there has been an increase in production and processing of cassava and most importantly how much cassava bread is being manufactured and consumed. The lesson here for the commercialisation of other orphan crops is that there is a need to build the business case as to why it is good or necessary to invest in adding value to these crops. At the same time, it is necessary for institutions to be in place to ensure that commercialising these crops does not negatively impact the communities that have relied on them for centuries and who have invested traditional knowledge in their cultivation and processing. There is a need for critical reflection on the food security impacts of cassava innovation. As a subsistence crop that is mainly used for food, industrialisation of the value chain (whether to make bread or other less staple foods) could have implications for food security (Ohimain, 2014).

The Andean region provides a good example where increased global demand for quinoa as a nutritious grain (the cultivation of which had fallen drastically by the late 1970s due, amongst other factors, to an increase in wheat imports) had left smallholders facing pressures of needing to cultivate to export market standards, but recognising the need to maintain crop diversity (Hellin and Higman, 2005). Hellin and Higman (2005) give some successful examples of NGO-led and public programs that have empowered local farmers to take advantage of markets and emerging technology whilst ensuring their livelihoods and local knowledge, but this is not a given. Navigating the ethical interaction between top-down formal technological innovation systems with bottom-up innovation processes happening within communities is a critical area for further investigation.

Finally, in terms of the actual invention of cassava bread technology, the IITA played a key role. As a transnational organisation based on the African continent, the IITA was able to leverage its capacity to work on a problem unique to the developing world- that of providing value addition to an orphan crop that is a mainstay of many African smallholder farmers. This points to the hypothesis that if achieving global food security is of paramount importance, then support for leading research organisations that are based in developing countries (and therefore close to developing world concerns) is paramount. The IITA and its collaborators have also been at the forefront of the biotechnological knowledge that has resulted in more resilient and more nutritious varieties of cassava being developed. At the same time, although the IITA could help in the development of the technology, it took direct government intervention to overcome the ‘chicken and egg’ situation of requiring both a stable supply of cassava as well as a market for HQCF. Good understanding of the need to develop strong links between actors and to identify the roles of different sectors is required to ensure the success of orphan crop innovation systems.

7 Conclusions

This paper puts orphan crops on the innovation agenda for delivering global food security in an uncertain future. Firstly, it emphasised why orphan crops provide an important element of novelty and diversity to the current food system, especially when importance is placed on involving marginalised farmers outside formal value chains. The paper then went on to use the case of cassava bread in Nigeria to illustrate the complexity of developing an innovation system that can successfully bring orphan crops from the realm of ‘minor’ to being ‘well-utilised’ crops. The long-term investment in cassava research in Nigeria was only part of the story, the biggest barriers to developing new markets for cassava to meet national priorities, came at the initial adoption and sustained use stages of the innovation system. Overcoming these barriers to successful innovation required institutional shifts in how the government approached the cassava transformation agenda.

Emphasis was placed on institutions that provide the incentives for innovation that is not aimed at meeting a specific market demand, but that can create a market for the types of products and technologies that can have sustainable benefits further up the supply chain. Orphan crops like cassava often suffer from being designated as inferior or 'backwards'– cassava is still viewed as 'the famine crop' whereas major crops like wheat and rice are seen as progressive or something to aspire towards being able to buy (See Van Oppen, 1991). Innovation that can break these stereotypes and create 'niche' markets for these products must form a critical aspect of any orphan crop innovation agenda. Furthermore, the bridging of formal innovation systems with the innovative potential embedded in the traditional knowledge sources that are often associated with orphan crops will require ethical institutions that recognise the power dynamics and inequities that could accompany interventions. This was distinctly lacking in the cassava example because it was purely an initiative driven from the top, due to the perceived importance of developing Nigeria's cassava value chain.

Although still a nascent field, the importance of developing innovation systems for orphan crops is going to become increasingly important as we face growing challenges in the food system to meet food security requirements. Learning from existing cases is the best way to move forward sensibly and to channel resources in the manner that will see sustainable and equitable outcomes- a resilient food system- rather than the mere delivery of yet another food product.

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