An *ex ante* economic impact analysis of developing low cost technologies for pyramiding useful genes from wild relatives into elite progenitors of cassava

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Abstract

This study conducts an ex-ante economic impact evaluation of developing low cost technologies for pyramiding useful genes from wild relatives into elite progenitors of cassava in Nigeria, Ghana and Uganda. More specifically, it estimates the change in economic surplus generated by introducing cassava varieties with tolerance to cassava mosaic disease, green mites, whiteflies, and delayed post-harvest deterioration. It compares the economic benefits of marker-assisted selection (MAS) to conventional breeding for these traits. Results indicate that varieties developed with marker-assisted breeding that incorporate all three traits are worth US$2.89 billion in Nigeria, $854 million in Ghana, and $280 million in Uganda over 20 years. If these varieties were to be developed with tolerance to CMD and Green mites alone they would be worth US$1.49 billion in Nigeria, $675 million in Ghana, and $52 million in Uganda if developed through MAS. If developed solely by conventional breeding they would be worth about US$676 million in Nigeria, $304 million in Ghana, and $18 million in Uganda. The difference is mostly due to the faster timing of release for the varieties developed with MAS and the higher probability of success. Several sensitivity analyses were conducted and benefits for MAS range from US$1.7 billion to US$4.3 billion for all three traits depending on assumptions. In all cases, the research investment is highly profitable from a societal standpoint.

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Chapter 1:

Introduction

In many developing countries, agricultural production represents a high percentage of total GDP, and rural household incomes depend almost entirely on agriculture (Camara, 2000). The range of agricultural products is often limited due to climatic conditions, marginal soils and water scarcity. Cassava (*Manihot Esculenta* Crantz) is a perennial root crop that grows in non-ideal conditions. Native to South America, cassava was introduced to Africa by the Portuguese colonizers (Cock 1985). It represents a major staple crop in Africa, South America and Asia. The relative importance of cassava arises from its adaptability to a wide range of agro-ecologies, including marginal lands and erratic rainfall conditions (Nweke *et al*., 1994).

Cassava is a cheap and reliable source of food for more than 700 million people in the developing world (FAO 2008). It is estimated that 250 million people in Sub Saharan Africa derive half of their daily calories from cassava (FAO 2008). Cassava is Africa's second most important food staple, after maize, in terms of calories consumed (Nweke, 2004). It provides very efficient carbohydrate production (de Vries et al. 1967; Coursey & Haynes 1970) and it can be used as food, animal feed, and to produce starch and alcohol. Through leaf consumption cassava also contributes substantial amounts of protein, minerals (iron and calcium) and vitamins (A and C), although to a much smaller population at the present time (Dixon, A. et al., 2003). It is the sixth major staple crop in the world (Mann, 1997) after rice, wheat, maize, potato, and sweet potato, with an annual production of 185 million tons (FAO, 2003).

Compared to other staple crops, cassava provides the possibility of maintaining a continuous food supply throughout the year through its long cropping cycle of 8-24 months (Nweke et al, 1994). Under optimal growing conditions, cassava is an efficient producer of carbohydrates. It is the most efficient product under suboptimal conditions of uncertain rainfall, infertile soils and limited inputs encountered in tropical areas (Loomis and Gerakis, 1975; Fregene and Puonti-Kaerlas, 2002). Africa is the lowest, Asia the highest, and Latin America is in the middle of the comparative spectrum in terms of yields (Johnson et al, 2003). Average world yield of fresh roots is about 10 metric tons per hectare, which is far below potential yields. Under optimal conditions cassava yields can be as high as 90 tons per hectare (Taylor & Fauquet, 1997). Yields depend on climate, soil fertility and inputs. As an insurance crop, cassava is often grown on poor soils with low inputs.

Approximately 57% of world cassava production is used for human consumption, 32% for animal feed and industrial purposes, and 11% is waste (Bellotti et al. 1999). In Africa, cassava is used almost entirely for human consumption. In Latin America, it is used for food and processed for animal feed, while in Asia cassava use varies from one country to another. The present trend is to increase the utilization of cassava in industry, especially to produce starch, as well as to promote its exploitation in biofuel industries.

Cassava is susceptible to a number of insects and diseases, namely whiteflies, cassava green mites (CGM), and cassava mosaic disease, among others. The use of costly inputs, such as pesticides, is not economical for the cassava producer in Africa. An important limitation of the potential of cassava as a crop arises from an endogenous chemical reaction that causes rapid post harvest physical deterioration (Reilly et al., 2007). Finding an economic way to deal with cassava's biotic stresses such as insects, diseases, and rapid post harvest deterioration, provides the key to opening the potential of cassava in fighting poverty and food insecurity in some of the poorest areas of the world.

Cassava breeders are broadening the genetic base and plant health researchers are using biological control, and other crop protection options, in order to continue to ensure food security in many tropical areas (Nassar and Ortiz, 2006). A Generation Challenge Program (GCP) project, led by scientists at the International Center for Tropical Agriculture (CIAT) in Colombia in collaboration with scientists and breeders from the national crop research centers in Nigeria, Ghana, and Uganda, has set off the process of introgression[1] of useful genes from wild relatives into cassava.

The project focuses on using molecular markers in breeding for desired traits in cassava. Markers reduce the number of generations required in backcross breeding from four to two (Hospital et al., 1992; Frisch et al., 1999). In order to derive a new variety of cassava with the desirable traits, conventional breeding requires from 12 to 16 years. The prolonged waiting period for results with conventional breeding methods increases the importance of innovative means for speeding up the process (Jung, 2000). It has been shown that the genetic potential locked up in cassava germplasm banks can be released

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[1] Introgression of a gene it the process of movement of a gene from one plant species into a gene pool of the same or another species.

effectively by “adopting molecular genetic maps and a modified Advance Back-Cross Quantitative Trait Loci (ABC-QTL) breeding scheme” (Tanskley and McCouch, 1997).

Genetic markers have become fundamental tools for understanding inheritance and diversity of natural variation (Fregene and Puonti-Kaerlas, 2002). Genetic markers permit the identification of progenies bearing the gene of interest with minimum genome introgression of the wild parent. Markers associated with the gene of interest also eliminate the need for time-consuming phenotypical evaluations.

Cassava gene pools in Africa have benefited from genetic variation found in Latin America where the crop originates. A systematic approach for evaluating wild cassava (*Manihot*) germplasm for resistance to insects and diseases has been set up. The goal is to evaluate existing and new collections for resistance to insects and diseases and build a database of results. Some key results have been achieved, such as the isolation of new germplasm for resistance to white flies, green mites, and mealybugs. Combined CMD and green mite resistance can be used in Nigeria, Ghana, Uganda, and combined CMD, GM and whitefly resistance in Uganda. Uniform and regional trials for lines with the mosaic disease and green mite resistance have been conducted in Nigeria, and on-farm trials are expected in 2008. Similar activities are under way in Ghana and Uganda. The release of new cassava varieties with combined mosaic disease and green mite resistance is expected in early 2009.

1.1 Problem Statement

Little economic analysis has been undertaken to assess the potential impacts of marker assisted selection for breeding of new varieties of cassava. If the breeding process is reduced by just a few years, potential gains can be very significant. Higher production would translate into larger profits and possibly poverty alleviation. Molecular breeding requires resources in order to target traits of interest related to resistance to insects and diseases. As a result, an economic impact analysis is important to assist in designing improved breeding programs, and would help policy makers, donors, international and national agricultural research programs set research priorities with a higher return on investment.

The current Generation Challenge Program (GCP) portfolio includes several projects with potential near-term technologies such as candidate genes identified and validated for traits of interest, DNA molecular markers linked to traits of agronomic interest, and germplasm with specific attributes. The Cassava GCP project has been partially implemented and an economic impact evaluation would provide estimates of potential benefits from this research investment.

The technical reports of the project detail the achievements to date, such as the collection of germplasm from wild relatives and isolation of genes conferring resistance to various insects and diseases. Cassava breeders in various countries will be able to incorporate these genes using marker-assisted breeding (MAB)[2] for developing new commercial cassava hybrids. Research and improvement of cassava has the potential to

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[2] MAS (Marker Assisted Selection) and MAB (Marker Assisted Breeding) are sometimes used interchangeably in the thesis. MAB is the larger breeding process where markers developed through MAS processes are utilized.

help reduce poverty in the least developed areas of the world. It has the potential to improve food safety for some of the poorer farmers in Africa, and with cassava's increasing feature as a cash crop, to improve their economic well-being in general (Felix Nweke, 2004).

Given the scarcity of research resources, prioritizing research with the highest return or greatest impact is important for research funding decisions. The results of research impact studies can provide useful insights for research funding decisions at local and state levels in Africa, Latin America and Asia and to support funding decisions of foundations and programs such as the GCP.

This study assesses the economic benefits of the cassava GCP program for breeding new varieties with MAS technology in Nigeria, Ghana, and Uganda. The expected economic benefits are compared against those of alternative investments, such as conventional phenotype-based breeding. The analysis specifies the distribution of the benefits among the different economic agents involved, indicating potential winners and losers.

1.2 Objectives

The objective of this thesis is to conduct an ex-ante economic impact evaluation of developing low cost technologies for pyramiding useful genes from wild relatives into elite progenitors of cassava. More specifically, it aims to estimate the change in economic surplus generated by introducing cassava varieties with tolerance to insects, diseases, and delayed post-harvest deterioration, and assess the distribution of benefits and costs between producers and consumers. It compares the economic benefits of marker-assisted selection (MAS) to conventional breeding in the case of cassava in Nigeria, Ghana, and Uganda.

1.3 Summary of Methods

The welfare effects of the new cassava technologies in the target countries will be projected using an ex-ante approach in an economic surplus framework. Variations of the economic surplus model have been adopted for the empirical analysis of ex-ante economic impacts of several new agricultural technologies. One of the advantages of the surplus model is that it can be modified to incorporate effects such as the type of market investigated, research-induced quality changes, and various externalities. Since fresh cassava is not a widely traded product, this study employs a closed economy model.

A small set of interviews were conducted with scientists and farmers in Nigeria, and questionnaires were sent to scientists in Ghana and Uganda. The interviews were conducted with scientists at the Agricultural Research Centers in the respective countries: the National Root Crop Research Institute (NRCRI) at Umudike, Nigeria; the Crops Research Institute (CRI) at Kumasi, Ghana; and the National Crops Resources Research Institute (NACRRI) at Kampala, Uganda. Secondary data on production and prices were gathered from FAO, IFPRI-Minnesota databases, and local sources in the countries studied. Demand and supply elasticities estimated by other studies conducted in the countries were used (Alderman, 1990; Nweke, 2002; Tsegai and Kormawa, 2002). The economic surplus models were run and sensitivity analyses conducted to estimate the total welfare gains under different scenarios.

1.4 Organization of the Thesis

A summary of the relative importance of cassava in Sub-Saharan Africa, an overview of marker assisted selection (MAS), utilization of MAS in cassava, and the status of research are presented in Chapter 2. A discussion of economic surplus analysis and a literature review is presented in Chapter 3. Economic surplus simulation results are presented in Chapter 4. A discussion of results and final conclusions are provided in Chapter 5.

Chapter 2:

Marker Assisted Breeding (MAB) and Technology Impact Pathways

The objective of this chapter is to summarize the importance of cassava as a commodity for Nigeria, Ghana and Uganda; present the target stresses; describe the process of marker assisted selection (MAS); and discuss the impact pathway.

Cassava is a staple food for millions in Africa, where population growth has driven an increase in its production for human consumption. In Sub-Saharan Africa, cassava is often produced in small farms on marginal lands. An estimated 70 million people obtain more than 500 Kcal per day from cassava (Kawano, 2003). The capacity of cassava to grow on poor soils and under difficult climatic conditions, in addition to the advantage of flexible root harvesting, make it the crop of last resort for human and animal consumption (Hillocks et al, 2001). Aerni (2006) stresses the importance of cassava as a food crop in Africa by comparing per-capita consumption to the rest of the world. The world average of annual cassava consumption was around 17 kg per capita in 2001, while Africa's annual consumption was above 80 kg per capita.

Fig. 2.1 presents the production, area and yield trends from 1980 to 2005. It is based on FAO data for all cassava producing countries, for Africa, and for the countries under consideration, Nigeria, Ghana and Uganda. Total world production increased over time, partly from an increase in the area where cassava is cultivated, and partly from increases in average yields. In terms of yields, Africa has lower yields than the average for the world, but Nigeria, Ghana and Uganda yields have been jointly higher than the world average since the mid 1980s.

It is noticeable that the increase in production in Nigeria has come mostly as a result of an increase in the area planted, with yields remaining approximately the same on average for this period. While Ghana has seen a slow increase in total production and area planted, it has also experienced continuous average yield increases from the early 1990s. The stable land use for cassava cultivation in Uganda, and especially the drop in production and yields in the 1990s, is as a result a severe form of the mosaic disease.

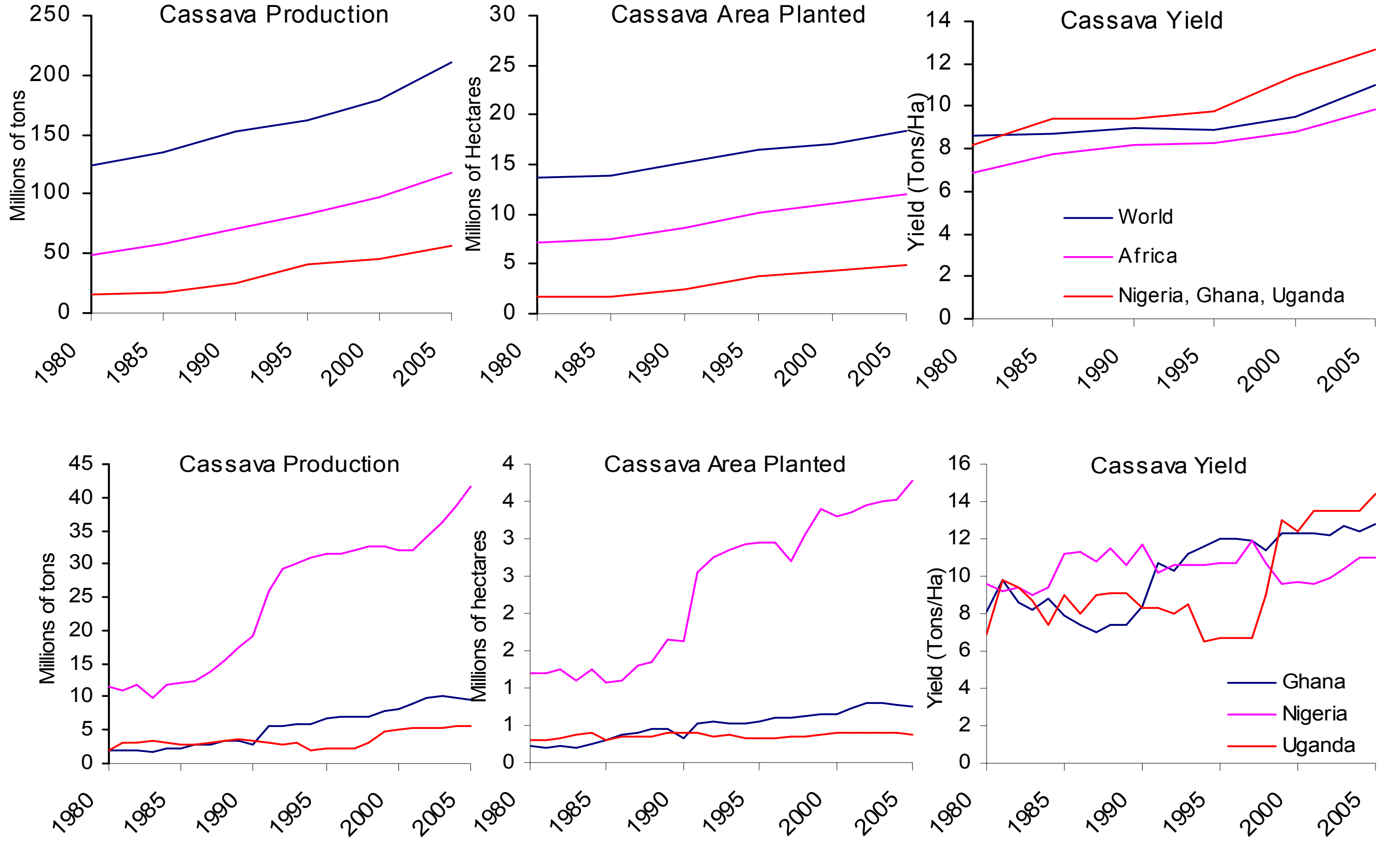

Fig 2.1. Production, area and yield trends for cassava from 1980 to 2005 (FAOSTAT, 2008)

Nweke (2002) reports that researchers with the COSCA[3] study in the early 1990s estimated the mean yield for local varieties in Nigeria at 13.41 t/ha while improved varieties yielded 19.44 t/ha. Nigeria more than doubled its cassava production between 1980 and 2005 (Table 2.1), but that is mostly attributed to an increase of land used for growing cassava rather than an increase in yield. Cassava production in Ghana doubled between 1980 and 2005, with an increase in average yield of 52% by year 2000. In Uganda, yield went up by 74% for the same period. Starting in the late 1980s and most of the 1990s, Uganda suffered a major decline in production when a variant of the cassava mosaic disease (CMD) spread throughout the country devastating the crop (Egesi et al 2007).

Table 2.1 Cassava Area, Production, and Yields from 1980-2005 (FAO, 2008)

Country	Year	Area (Ha)	%Δ	Production (MT)	%Δ	Yield (Kg/Ha)	%Δ
Nigeria	1980	1,200,000		11,500,000		9,583	
	2005	3,782,000	315%	41,565,000	361%	10,990	115%
Ghana	1980	230,000		1,857,600		8,077	
	2005	750,000	326%	9,567,000	515%	12,756	158%
Uganda	1980	302,000		2,072,000		6,861	
	2005	387,000	128%	5,031,000	243%	14,408	210%

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[3] COSCA – The Collaborative Study of Cassava in Africa was conducted in several East and West African countries. For a list of papers from this study see: http://www.fao.org/ag/AGP/AGPC/gcds/gcs_files/subpages/05cosca.htm

2.1 Target Stresses

Due to its long cropping cycle, cassava is exposed to an array of insects, diseases, and environmental pressures for an extended period of time (Dixon et al. 2003; Oerke 2006). Pests such as the whitefly, which carries the cassava mosaic disease (CMD), and cassava green mites (CGM), have a wide spread in Africa (Nassar and Ortiz, 2006). Cassava is also affected by an endogenous root disorder known as post-harvest physiological deterioration (PPD).

The Cassava Mosaic Disease (CMD) is a viral disease transmitted by white flies which on average destroys about a third of the crop each year (Eicher et al 2006). It is the most devastating cassava disease on the African continent and leads to genetic erosion of local African cassava germplasm (Kizito et al. 2006). Fauquet and Fargette (1990) measured crop losses from the CMD in several African countries and found large losses in each of them. They found that crop losses in Nigeria ranged from 20% to 90%, in Ghana about 25%, and in Uganda from 55% to 87%. Legg and Thresh (2000) estimated that, of Africa's total production of 97 million tons in 2003, losses to CMD accounted for 19 to 27 million tons, representing an annual loss of about US$3 billion.

Between 1998 and 2003, Nigerian farmers saw an exponential increase in the spread and number of recombinant types of this virus (Ogbe et al. 2006). The mosaic disease is very adjustable and evolves fast. As a result its development is closely monitored for preventative measures against possible changes in resistance. The severity of the effects of the cassava mosaic disease is often dependent on environmental factors. For example, the southern part of Nigeria is especially prone to the disease because of high humidity. Producers and consumers in southern Nigeria suffer larger negative effects of the mosaic disease as cassava is grown and consumed more extensively than in the north of the country. Legg and Fauquet (2004) map the the spread of cassava mosaic viruses in Africa, depicting the types of virus present, such as the African CMD (ACMV), East African CMD (EACMV), and the East African CMD – Ugandan Variant (EACMV-UG).

Whiteflies (*Bemisia tabaci*) are known as a pest of field crops in tropical and sub-tropical regions. Some whitefly biotypes within Africa appear specifically adapted to cassava, causing severe losses to the crop. While feeding damage can cause economic losses, it is the ability of whiteflies to transmit or spread viruses that has had the widest impact on cassava production. This ability to serve as a carrying vector of the cassava mosaic disease has made it one of the most devastating pests throughout Africa. Chemical control for whiteflies has been ruled out because of concerns that it will destroy the natural enemies of whiteflies as well.

Cassava green mites (*Monoychellus tanajoa*) spread to more than 30 countries by late 1980s and considerable damage to cassava crops (New Agriculturalist Online, 1998). Damage caused by the green mites depends largely on the length of the dry season. For example, Northern Nigeria is comparatively affected more by green mites than the South, because it has a longer dry season. In several east and central African countries, yield losses of 10-80% have been recorded (Shukla, 1976; Markham and Robertson, 1987). If the dry season is prolonged, there is a higher probability of a build up of green mites and increased losses. Skovgard et al. (1993) studied the effects of green mites in Kenya and found that after 10 months, the dry matter was reduced by 29% in the storage roots and

21% in the stems. Chemical control is not economical for green mites, and some scientists believe that bio-control can work well.

The deterioration of fresh cassava roots soon after harvest, caused by a number of bacteria, represents the central constraint to the development of cassava as a cash crop. Within one to three days of harvest, cassava roots exhibit a blue–black discoloration and other unpleasant changes (Reilly et al., 2007). This rapid deterioration constrains the development of cassava by reducing the marketability of fresh unprocessed cassava. Losses from postharvest physiological deterioration (PPD), insects, and diseases, have been estimated at 30% of the total world production (GCP Project 9(SP3) Proposal, August 2004). PPD poses a severe problem to producers and consumers alike, especially affecting poor farmers in Sub-Saharan Africa who are both producers and consumers. Current post-harvest management practices used to extend the storage life of cassava roots are either technically or economically unsuitable for most farmers in Africa.

2.2 A description of Marker Assisted Selection in Breeding

Innovations in molecular biology, such as the development of markers and molecular mapping, have provided new tools for the understanding, isolation and classification of complex traits of interest. An example of this is the identification of genes related to traits of interest, such as multiple disease resistance and delayed post-harvest physiological deterioration.

Marker assisted selection (MAS) is a process, at a genetic level, in which a molecular marker is used for indirect selection of determinants of a trait of interest. Marker assisted breeding, a process in which marker assisted selection is used, is carried out with the assistance of identifiable traits. When a mutation is found in a plant, or a close biological relative, scientists isolate the responsible gene. When the mutant is found in close proximity to the gene of a desired trait, then the marker is linked to the gene. The gene is put on a genetic map which indicates its recombination frequency relative to other genes (Okogbenin et al., 2006). Genes that are close in a genetic map are usually carried over in breeding crosses. Ruane and Sonnino (2007) noted that molecular marker maps have been created for a number of different plants, but the density of the maps varies from one plant to another. Scientists are in the process of completing the map of cassava genome.

The marker gene is used to determine whether a breeding cross has transferred the desired trait. If the marker gene is found to be present, it is highly probable that the desired trait will be present in the progeny (Ribaut and Hoisington, 1998). A marker allele which is linked with the gene of resistance is utilized to establish the presence of resistance in the genotype. Disease resistance in plants is a fairly simple type of trait, as it is controlled by one or a few genes (Young, 1999). Some traits can be genetically complex involving many genes, or quantitative trait loci (QTL)[4], and environmental effects.

The success of MAS depends upon several critical factors, including the number of target genes to be transferred, the number of genotypes selected in each breeding generation, the biology of the germplasm and plant, and other things. Brennan and Martin (2007) state that there are significant perceived gains from incorporating some of the new technologies in breeding programs. They discuss the potential benefits from using MAS

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[4] Quantitative Trait Loci (QTL) are stretches of DNA within plant genomes that are closely linked to the genes of interest (Collard et al., 2005).

in a wheat breeding program, and state that MAS breeding operations may be conducted at a fraction of the cost of conventional breeding.

Molecular markers differ in a number of ways, including technical requirements, resources needed for their application, the number of them that can be detected throughout the specific genome, as well as the amount of genetic variation found at each marker in a given population (Ruane and Sonnino, 2007). The success of MAS is influenced by the relationship between the markers and the genes of interest. Dekkers (2004) points out three types of interactions between markers and genes of interest: (1) the molecular marker is located within the gene of interest, which is the most favorable situation referred to as gene-assisted selection. These types of markers are rare and very difficult to find. (2) The marker is in linkage disequilibrium (LD) with the gene of interest in the entire population. Linkage disequilibrium in the population of interest usually can be found when markers and genes of interest are physically very close to each other or when lines have been crossed in recent generations. (3) The marker is not in linkage disequilibrium with the gene of interest in the population. Selection using these markers represents the least favorable situation for using MAS in plant improvement programs (Dekkers, 2004).

There are several situations that scientists identify as cases where it is favorable to use marker assisted selection for identifying the traits of interest: (1) the desired trait is expressed late in plant development; (2) the target gene is recessive in nature; (3) there is a requirement for the presence of special conditions in order to invoke expression of the target gene; (4) the genes are unstable in different environments; (5) there are multiple unrelated genes affecting the targeted trait; (6) multiple traits are targeted at the same time, such as gene pyramiding. Servin et al (2004) created a simulation study aimed at finding the best gene pyramiding scheme based on the probability of success of several MAS procedures. The results were compared to a reference genotype selection method with random mating (conventional breeding). They found that “the best gene pyramiding method combines the eight targets in three generations less than the reference method while requiring fewer genotypings” (Servin et al, 2004).

2.3 Potential benefits of Marker Assisted Breeding (MAB) in cassava

The benefits of incorporating markers in breeding programs will likely differ depending on the program (Brennan and Martin, 2007). In a growing number of instances markers have been shown to be lower cost than conventional methods (Bonnett et al, 2005; Kuchel et al, 2005). A list of potential benefits has been developed by reviewing cassava GCP project proposal and report updates, and by discussing with the scientists involved in Nigeria. Some of the specific benefits of incorporating MAS in cassava breeding programs in Sub-Saharan Africa include: (1) a considerably shorter time period to develop new varieties. A much earlier variety release with desired traits, than would be achieved using conventional breeding, would benefit farmers and consumers. The main aspect is that the time required in determining whether a trait is present is greatly reduced with a direct way to find the genes of interest. A second part contributing to this is the elimination or acceleration of several steps in the breeding process. (2) Potential higher new variety adoption. Because breeding with MAS can introduce varieties with multiple traits of interest, there might be a higher adoption among farmers, especially since the first variety to be released has CMD and GM resistance, and the varieties to be released later will have d-PPD incorporated too. (3) Breeding cost reduction. The breeding programs of NARES in the target countries will benefit from the gene maps created at international centers like CIAT. Breeders will not need to spend considerable resources and time trying to identify traits of interest using phenotypic evaluations. Instead, they will have direct access to the genes of interest which then can be easily incorporated into their breeding lines. (4) An increase in the overall rate of genetic gain in a breeding cycle. By allowing the ready introduction of desirable traits in combination, the varieties produced using molecular markers can be more productive than those developed by conventional breeding methods. There will be smaller or no genetic loads into the new varieties, as well as breeders may incorporate multiple traits simultaneously. (5) An increased probability of identifying desirable traits. This increased probability is possible with the aid of MAS because the specific genes responsible for the trait can be directly targeted, instead of following a long process of phenotypic evaluations which can end without success. (6) New desirable traits can be found. Scientists at CIAT have found genes responsible for high protein levels when they were looking for high carotene. (7) Faster access to new genes provides greater genetic diversity. Molecular markers allow the breeder to identify diversity at an early stage, which can be maintained throughout the breeding cycle.

Despite the promises and potential that MAS presents to plant improvement programs, some scientists have voiced concern that the number of success stories is still very small. Young (1999) states that even with the added importance of marker-assisted selection in plant breeding, there are only a few successful outcome examples. According to this study, molecular markers hold a great promise for its application in various breeding programs, but its realization still remains elusive. Ruane and Sonnino (2007) point out that marker assisted selection still does not play a major role in genetic improvement programs in any of the agricultural sectors.

Dekkers and Hospital (2002) found that advances in molecular technology will soon create a wealth of information that can be exploited for the genetic improvement of plants, but the methods to effectively analyze and use this information are still to be developed. They further note that until complex traits can be fully broken down, applications of MAS will be limited to genes of moderate-to-large effects, and that conventional improvement programs will remain key parts of plant breeding programs.

According to a number of studies (Brennan and Martin, 2007; Morris, 2003), as well as scientists that were surveyed, some factors moderating the benefits from using molecular markers in the GCP cassava breeding program include: (1) the high cost of markers which might not be economical for small breeding programs; (2) for clearly distinguishable traits it may be favorable to use phenotypical evaluation instead of MAS; (3) for certain complex traits, there could still be a lower cost technology that is different than molecular markers; (4) when marker correlation with characteristics identified by phenotypic screening is incomplete, breeders face uncertainty as to the extent to which they can rely on the marker rather than the phenotypic screening; (5) although markers for particular resistance against insects or diseases can be valuable, the ever-evolving nature of such diseases means that other phenotypic evaluation will still be needed.

There has been some discussion about the costs of using MAB versus conventional breeding. Dekkers and Hospital (2002) emphasize the importance of costs as the key determinant for the application of molecular genetics in plant improvement programs. They list a number of costs incurred when using molecular techniques, such as the cost of QTL detection, DNA collection, genotyping and analysis. Koebner (2003) noted that current costs of MAS need to fall significantly before it can be used more widely in breeding programs.

Morris et al. (2003) considered the transfer of an elite allele at a single dominant gene from a donor line to a recipient line in maize, and found that conventional breeding is less expensive but MAS is quicker. In such cases, where the choice between conventional breeding and MAS involves a trade-off between time and money, they suggest considering: (1) the relative cost of phenotypic versus marker screening; (2) the time saved by MAS; (3) the size and temporal distribution of benefits related to the accelerated release of improved germplasm; (4) the availability of operating capital. They further conclude that given the variation between breeding projects, a detailed economic analysis may be needed to predict the optimal methods for a given breeding project.

An important distinction exists between MAS development costs, such as identifying molecular markers on the genome or detecting associations between markers and the traits of interest, and MAS breeding running costs, such as typing individuals for the appropriate markers in the selection program. Development costs represent a considerable portion of the total costs associated with MAS selection, and as a result national crop research centers need to consider whether it is preferable to develop their own technology or to cooperate with international institutes and use their technology. In the case of cassava, the International Center for Tropical Agriculture (CIAT) in Colombia plays a key role in providing national agricultural research and extension services (NARES) with molecular markers for their breeding programs.

For smaller breeding programs it may not be economical to incorporate markers into their program. In the case of the cassava GCP, cooperation between international and national centers has been established. This makes it possible for Latin American markers to be used in Africa, while in the same time these markers are being saved in gene banks for future use. In the meantime, scientists are continuing to develop new lower cost markers which will increase the attractiveness of MAB (GCP Project 9(SP3) Update Report, October 2006). In conclusion, when considering marker assisted breeding versus conventional breeding, the key factor to consider is the existence of a strong breeding program as a precondition for the application of MAB. Marker assisted breeding will not be possible if the infrastructure and capacity of a breeding program are insufficient to support a successful conventional program (Ruane and Sonnino, 2007).

2.4 Technology Impact Pathways of Marker Assisted Breeding

Impact pathways provide information on the new varieties of cassava being developed, the timing of release, and the area of impact for new cassava varieties. The benefits from improved varieties through breeding have been demonstrated in several cases, both in relation to the international agricultural research centers and national programs (Brennan et al. 2007). It has been acknowledged that resistance to diseases provides the pathway to cassava reaching its full potential in fighting food insecurity and even poverty. Targeting these stresses is crucial for the development of cassava in Sub-Saharan Africa and beyond. Scientists and breeders at international and national crop research centers have been working to breed resistance to these stresses in new varieties of cassava through the use of novel and promising technologies such as marker assisted selection (MAS).

In conventional cassava improvement programs, without knowing exactly which genes are actually being selected, selection is carried out based on phenotypical evaluation of the candidates for selection. An obstacle with conventional breeding is the "linkage drag", that is undesirable genes present in the region where the target gene is located. This genetic load is brought along when the target gene is transferred into the new cassava variety. The main concern with linkage drag is that it may bring undesired genes, which might negatively affect the performance of the new variety. Linkage drag causes the need for additional backcrosses, and often the undesirable traits may be difficult to eliminate using conventional breeding alone (Collard and Mackill, 2008). As a result, breeding programs are moving from phenotype-based towards genotype-based selection (Ruane and Sonnino, 2007).

The heterozygous nature of cassava plants, and the primary method of vegetative propagation, further reduce genetic diversity over time because of the accumulation of systemic pathogens and the spread of a few, vigorous, well-adapted landraces able to produce many planting stakes (Fregene et al., 2000). On average, cassava plants can produce 6 to 8 seedlings, and only one cross per year is possible. Some plants, for example maize, provide a large number of seeds and can be crossed several times during a year. For traits that are difficult to identify in the cassava genome, conventional breeding may take 15 to 20 years, often with very low probability of success. If breeders aim at breeding for multiple traits at the same time, the probability of success with conventional breeding is even lower. As a result, marker assisted selection is important for traits that are difficult to measure, exhibit low heritability, or are expressed late in development.

A key aspect of using MAS is that traits of interest can be identified, isolated and transferred without being in a specific agro-ecology. The high level of uncertainty related to conventional breeding is that even if one thinks that a trait is present, confidence is only established after many field trials. Markers reduce the amount of germplasm a breeder needs to carry at every stage of breeding and evaluation. Markers have also aided better understanding of the genetics of cassava, since much less was known before this technology was available.

The breeding stages for resistance to the mosaic disease, whiteflies, green mites, and the introgression of a gene related to delayed post-harvest physiological deterioration with marker assisted breeding are presented in Table 2.2. It shows the most probable[5] MAS breeding stages as opposed to conventional breeding. By using MAB, a breeding program can achieve results at least 4 years earlier compared to conventional methods. Preliminary and advanced yield trials are skipped as these are unnecessary once the genes of interest have been identified. The uniform or regional trial periods are reduced from 4 to 2 years, because in these stages with MAB only the presence of the genes of interest and its performance are tested. Some of the other breeding stages can be shortened, such as clone evaluation, which could potentially be completed in 12-16 months.

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[5] This is the most probable scenario based on the opinion of scientists and breeders surveyed.

Table 2.2. Cassava breeding stages with conventional and MAS technologies

Activity	Year (Conventional Breeding)	Year (Marker Assisted Breeding)
Female x Male	Year 0	Year 0
F1 and Clone evaluation	Year 1-2	Year 1-2
Preliminary yield trials	Year 3	**Skipped**
Advanced yield trials	Year 4	**Skipped**
Uniform/Regional Trials	Years 5-8	Years 3-4
On farm trials	Year 9	Year 5
Variety release	Year 10	Year 6
Multiplication[6]	Years 11-15	Years 7-11
Total Number of Years	***15***	***11***

Source: C.N. Egesi and E. Okogbenin (2008): personal communication.

Genetic improvement of crops depends on the extent of genetic variation present in available germplasm (Paterson et al., 1991). The Cassava GCP project has generated 60 new materials of resistance from reliable sources, 11 of which are ready to go into uniform trials. In Nigeria, uniform trials were being finished in the middle of 2008, while variety CR-14A/1 was in on-farm trials. The new materials are saved in germplasm banks, so they can be available to other countries and for use in the future. The cassava germplasm bank at CIAT contains nearly 6,000 genetic accessions (Okogbenin et al., 2007). The largest portion represents traditional cultivars that result from centuries of farmer selection and cassava cultivation in various environments (Bellotti and Arias, 2001).

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[6] Note: Multiplication presently takes 5 years on average, but it could be cut to 2 years if managed by breeders with additional resources.

The goal of the CIAT-led Cassava GCP Project is to develop low-cost molecular markers in a way that once completed such technology can be easily accessed. In this regard, according to the scientists involved the project developed Sequence Characterized Amplified Regions (SCARS), which are easy to use by other scientists, for cassava mosaic disease (CMD) resistance. The Cassava Mosaic Disease (CMD) is the most devastating disease for cassava plants throughout Africa, and the pyramiding of multiple sources of resistance can enhance durability of resistance to this disease. The identification of markers associated with delayed PPD and the initiation of development of markers for efficient transfer to African cassava gene pools have been achieved (GCP Project 9(SP3) Update Report, October 2006).

The identification of candidate markers for resistance to cassava green mites (CGM) has also opened up possibilities for introgression of this trait into well adapted gene pools. Studies are ongoing to identify markers for new sources of resistance for CMD and CGM, and similar efforts are underway to achieve resistance to whiteflies. An advanced backcross QTL technique is used to transfer resistance to insects and diseases and delay post-harvest physiological deterioration. Evaluations of new collections of cassava relative species, Manihot family, for desirable traits are ongoing with the aid of marker-aided introgressions. More than 500 accessions of 12 wild cassava (*Manihot* family) species have been collected in water-stress areas of Brazil where insects and diseases are endemic (GCP Project 9(SP3) Update Report, October 2006).

The greatest revolution stemming from the use of MAS in cassava is the identification of delayed post-harvest physiological deterioration (d-PPD). The delayed PPD is in the in-vitro propagation stage at CIAT and the markers are expected to be available for some of the breeding programs in Africa by 2009. These markers will be evaluated in Nigeria, Ghana, and Uganda, since they need to be tested in the respective environmental conditions. With the increased production, farmers might have more money to improve agricultural practices and their livelihoods. A new variety with delayed PPD will increase fresh cassava marketability in all the countries in Sub-Saharan Africa. In most South American and Asian countries chemical protection methods, such as paraffin, are used to prevent PPD and achieve fresh cassava marketability. This type of chemical conservation is not economical for the African farmer. At present only a small fraction of fresh cassava produce is marketed further than the local farmer's markets. Delayed PPD could cause fundamental changes in the markets for cassava in Africa, where cassava could be stored, traded and transported longer distances.

According to local scientists, the problem of the multiplication of seedlings is an important issue because of limited resources of NARES and its management by government extension agencies, such as Agricultural Development Programs (ADPs) in Nigeria. Breeders at NARES could take the additional responsibility of multiplying and disseminating new variety seedlings. These dissemination channels explain in part the reasons why many of the new varieties released in the past have not reached all farmers.

Cassava differs in terms of genetic variation from other food staples, such as maize, because its domestication has not been completed. As a result, scientists can look for genetic variation in wild relatives. In this fashion, numerous useful traits have been found, such as high wax, protein, and carotene levels. Cassava can also be utilized in producing ethanol, but currently it is not as efficient as other plants. Several projects in the near future may aim at adding some new traits to cassava such as starch content, betacarotene, vitamin A content, protein content, and other desirable traits. These developments may affect the nature of cassava’s markets, its usability, and may affect food security in Sub-Saharan Africa.

Chapter 3:

The Economic Surplus Methodology, Data and Assumptions

This chapter discusses the methods used in assessing the impacts of marker assisted selection (MAS) technologies in cassava breeding, as well as the data used in the analysis and assumptions. Economic impact assessment of new technologies provides researchers, scientists, and decision-makers information and knowledge on the benefits and costs of the research involved. Information on the expected benefits and costs of alternative research strategies can be used to set research priorities, to design research, and to evaluate research. Economic benefit evaluations are separated into two general types based on the timing of analysis: an *ex-ante* evaluation provides a basis for allocation resources among competing research demands, *ex-post* evaluation provides estimates of realized economic value of research in the past. Ex-ante studies are based on projections made by researchers, extension workers and social scientists regarding yield, likely success rate, and adoption of the new technology.

Certain approaches for economic evaluation of agricultural research are commonly applied in the economics literature. The economic surplus model is often used for analyzing *ex-ante* the welfare effects of agricultural research in a partial equilibrium framework. An economic surplus framework considers per unit cost reductions and price responses to research-induced quantity shifts and assesses the level and distribution of research benefits. The model shows to what extent research-induced reductions in per unit cost of production and in adoption by farmers, may reduce market prices (Norton and Dey, 1993).

Economic surplus analysis measures the changes in terms of producer surplus (PS) and consumer surplus (CS). Producer Surplus (PS) is the return to quasi-fixed factors of production from selling a good at the equilibrium price, while Consumer Surplus (CS) reflects the consumer's willingness to pay more for a good than the market price (Marshall, 1980; Mishan, 1981). Economic surplus analysis considers the nature of the market for the commodity and the fact that prices may fall as production changes and supply increases. Market effects stemming from whether the product is widely traded are considered. In the case of fresh cassava in this study in Africa, the closed economy model is used since cassava is not traded extensively. The economic surplus method measures the change in producer and the consumer surplus, where the resulting total welfare change is the sum of the two (Fig. 3.1).

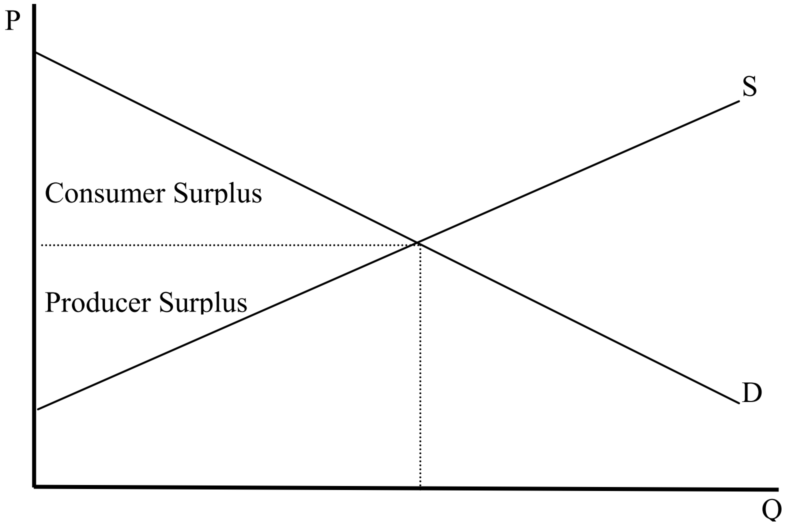

Fig 3.1. The separation of consumer and producer surplus.

In his discussion of the method, Harberger (1971, p.785) laid down three assumptions that must hold for conducting an economic surplus analysis: "(1) the competitive demand price for a given unit measures the value of that unit to the demander; (2) the competitive supply price for a given unit measures the value of that unit to the supplier; and (3) when evaluating the net benefits or costs of a given action (project, program, or policy), the costs and benefits accruing to each member of the relevant group (i.e. family, city, state, nation, world) should be added without regard to the individuals to whom they accrue."

The size and nature of the shift in the supply curve influence the distribution and total benefits. Total benefits from a parallel shift are almost twice those from a pivotal shift. Norton et al. (1992) suggest using a vertically parallel shift for simplicity and consistency in evaluating the different programs for different commodities. According to their study, producers always benefit from a parallel supply shift while they only benefit from a pivotal shift when demand is elastic. One of the most important parameters in the economic surplus analysis is the research induced proportionate shift in supply (the **K** factor). For a change in total surplus (TS), which is change in consumer surplus (CS) plus change in producer surplus (PS), in a closed economy with linear demand and supply and a parallel research induced supply shift, we have (Alston et al., 1995):

$$\Delta TS = P_0 Q_0 K (1 + 0.5 Z \eta)$$

$$\Delta CS = P_0 Q_0 Z (1 + 0.5 Z \eta)$$

$$\Delta PS = P_0 Q_0 (K - Z)(1 + 0.5 Z \eta)$$

Where: P_0 and Q_0 are initial equilibrium price and quantity, respectively

$Z = K\varepsilon/(\varepsilon + \eta)$ relative reduction in price due to supply shift

ε = supply elasticity

η = demand elasticity (absolute value)

K = shift of the supply curve as a proportion of the initial price

By Alston et al (1995, p. 360), the proportionate shift of the supply curve **K** can be calculated as:

$$K = (E(Y)/\varepsilon - E(C)/1+E(Y))\ p\ A_t\ (1\text{-}dt)$$

Where: E(Y) = expected proportionate yield Δ (per Ha) from adoption of new technology

E(C) = expected proportionate Δ in variable input costs (per Ha) from adoption

p = probability of success of achieving the expected yield Δ from adoption

A_t = adoption rate of technology in time *t*

d_t = rate of depreciation of the new technology

One of the drawbacks of the economic surplus method is that it generally ignores transaction costs, which results in overestimation of benefits from activities with high transaction costs. Alston *et al* (1995) argue that the partial equilibrium nature of the analysis ignores the effect of any relationship with other products and factors in the market and the issue of measurement errors associated with economic surplus analysis. They state that other methods, such equivalent variation (EV), may be more accurate than the surplus method as it also takes into account the income effect of the price change. However, they further point out that errors associated with the assumptions regarding the demand and supply elasticities, nature of the supply shift, research lag and adoption, etc., are of greater magnitude than income effects. Given the limitations in evaluating the future benefits of a research program, the partial equilibrium economic surplus model represents the most widely used approach.

When widespread adoption of the new technology occurs across large areas, changes in crop prices, cropping patterns, producer profits, and societal welfare are probable. These changes arise because costs differ and because supplies may increase, affecting prices for producers and consumers. A graphical illustration of these changes is provided in Figure 3.2. In the graph, S_0 represents the supply curve before the adoption of the new technology, and D represents the demand curve. The initial price and quantity are P_0 and Q_0. Suppose the cassava research leads to savings of R in the average and marginal cost of production, reflected in a shift down in the supply curve to S_1. This shift leads to an increase in production and consumption of Q_1 (by $\Delta Q = Q_1 - Q_0$) and the market price falls to P_1 (by $\Delta P = P_0 - P_1$). Consumers are better off because they can consume more of the commodity at a lower price. Consumers benefit from the lower price by an amount equal to their cost saving on the original quantity (Q_0 x ΔP) plus their net benefits from the increment to consumption. Total consumer benefits are represented by the area P_0abP_1.

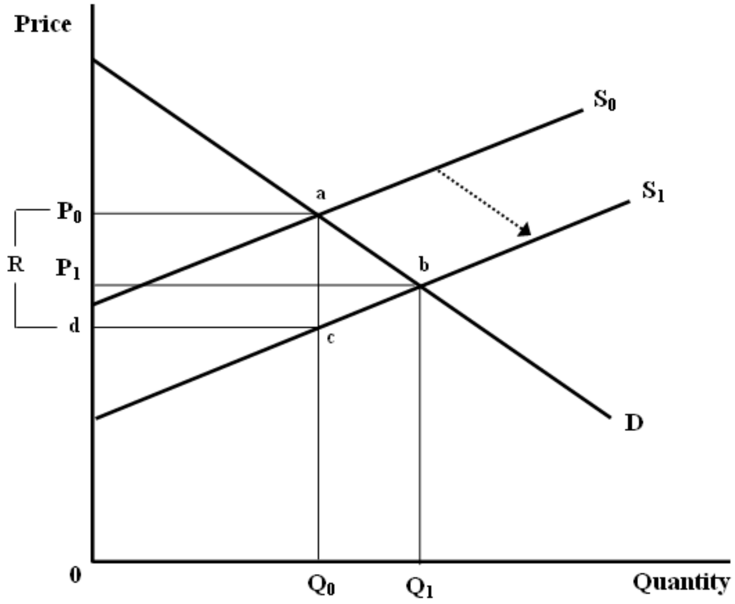

Fig 3.2. Cassava GCP Benefits Measured as Changes in Economic Surplus (Adopted from Norton et al, 2005)

Norton et al. (2005) state that producers may receive a lower price per unit, but they are better off because their costs fall by a greater amount. They further conclude that the distribution of benefits depends on the amount by which the price falls compared to that of costs, as well as the shape the supply shift takes. If the supply curve shifts in more of a pivotal fashion as opposed to a parallel fashion as illustrated in Figure 1, the benefits to producers would be reduced.

Calculating the proportionate shift in supply following the new technology adoption is the most challenging aspect in a surplus analysis, because cost changes and adoption rates must be predicted. Surveys providing information on cost and yield changes in field trials can be used to obtain the information required to estimate the supply shifts. Once changes in economic surplus are projected over time, we provide net present values (NPV), internal rates of return (IRR), benefit-cost ratios, and further conduct sensitivity analyses that is helpful considering the *ex-ante* nature of the evaluation. The benefits are the change in total economic surplus calculated for each year, and the costs are the expenditures related to developing the new cassava varieties. The surplus analysis takes into account discounting, since the sooner benefits occur the more they are worth. The net present value (NPV) of discounted benefits and costs is calculated as follows: $NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+i)^t}$ where: R_t = the return in year t; C_t = the cost in year t; i = the discount rate. The internal rate of return is the interest rate that makes the net present value equal to 0, measured as $\sum_{t=1}^{T} \frac{R_t - C_t}{(1+IRR)^t} = 0$.

Aggregate or market level economic effects can be distributed in a variety of ways and have other social and economic effects at the household level. Therefore an *ex-ante* assessment of welfare effects of the cassava research programs may not end but rather just begin with the prediction of market-level economic impacts.

3.1 The Surplus Model in Economic Literature

Alston et al. (1995) provide an extensive review of models used in the economic evaluation of agricultural research. They discuss both the economic surplus analysis approach and econometric methods used in estimating the economic benefits of research on new agricultural technologies. Econometric estimation is suitable for ex-post studies where the effect of past investments in research can be estimated using data on inputs, outputs, and research expenditure. The economic surplus method is used in both ex-ante and ex-post studies and is one of the most commonly used. Several empirical studies apply economic surplus in evaluating impacts stemming from new agricultural technologies. These studies treat specific new technology evaluations in diverse market contexts.

Norton et al. (1987) estimated the potential benefits of an agricultural research and extension program in Peru. The study examined the effects of demand shifts over time and the influence of the government pricing policies on research benefits. Pimental et al. (1992) estimated the environmental and social costs from pesticides in the United States. This study concluded that applying pesticides costing \$4 billion resulted in \$16 billion in savings for a given year, but the environmental and social costs amounted to \$8 billion. They pointed out that environmental costs associated with the use of chemical pesticides are not considered at the farm level.

Mills (1998) evaluated the potential impact of public sector maize research with and without trade barriers to foreign trade in Kenya. The study used an ex-ante technique, and emphasized the importance of relaxing the trade barriers in for the benefit of consumers. The lower prices were especially important because population growth was predicted to cause difficulty in maintaining self sufficiency. Debass (2000) used partial budgeting and ex-ante economic surplus analysis to estimate the aggregate benefits of the IPM-CRSP strategies in Bangladesh and Uganda. The study provided evidence that the welfare benefits were shared both by consumers and producers, and IPM strategies were more profitable than farmer practices.

Hareau et al. (2005) used ex-ante evaluation of the economic impact of herbicide resistant transgenic rice in Uruguay. They used a stochastic simulation technique to estimate how benefits vary with changes in technology, yield, costs, and adoption parameters. They found that the benefit for the multinational company that would develop the technology was $0.55 million. Kostandini et al. (2006) applied the economic surplus model under imperfect competition to show the potentials of biopharming by looking at the transgenic tobacco case. Their results suggest that in a market with patent rights only the innovating firm will benefit, while consumer benefits are unlikely. Moyo et al. (2007) created a procedure for predicting *ex ante* impacts of agricultural research on aggregate poverty. This procedure was applied to estimate the poverty-reducing impact of peanut research in Uganda. They combined market-level information on economic surplus changes with a procedure for allocating income changes to individual households.

These are just a few examples of the many studies which have used the economic surplus analysis to evaluate impacts of agricultural research.

3.2 Measuring the Impacts of the Cassava GCP MAS Project with the Surplus Model

The total economic contribution of the Cassava MAS project will be projected based on the situation with the new technologies as compared to the most likely situation without the new technologies. The impacts will be calculated for a period of 20 years, taking into account the following: (1) area of the crops currently being affected by the target stresses, projected changes in planted area, and production of the crops in specific countries; (2) the nature of the markets for the crops; (3) the projected yield and cost changes due to the new technologies; (4) the estimated time for discovery, development, and deployment of the DNA marker technologies and associated donor germplasm; (5) the estimated time required to breed, test and disseminate superior new cultivars, including the rate of adoption by farmers, and (6) the discount rate for benefits and costs that occur in the future.

Technological change due to research in agriculture can increase yields or reduce the cost of production. If the new technology is yield increasing the producer sells more of the good and, given a downward sloping demand, the price of the good decreases. A cost-reducing technological change allows the producer to sell the same quantity as before but at a lower price. The final effect of the technological change is for both cases a reduction in the cost of production per unit of output, whether by producing an increased output with the same cost or by reducing the cost of producing the same amount of output. In both cases, a new equilibrium is formed due to a shift in the supply curve, and the new equilibrium is attained at a lower price and a higher quantity demanded.

Technology-impact pathways were constructed by reviewing technical reports and surveying scientists involved. These impact pathways clarify the intended geographic area of impact, timing of various components of the research and adoption, and the relationship of the research to other activities. Information on the current status of development of the various products was obtained from the scientists working on the research. Secondary data on cassava production, area, prices, and trade were gathered for Uganda, Nigeria, and Ghana, drawing in part on the IFPRI/Minnesota database, FAO STAT, and some local sources. Data on crop losses for major cassava diseases, insects, and post-harvest physiological deterioration were also collected. An expert survey was conducted in each country, in which scientists and other cassava experts were asked to estimate crop losses in an average year attributable to the various stresses.

Data on yields and input costs were gathered from previous field trials and previous surveys with cassava farmers. These were combined with output prices to enable construction of budgets for each location. Where sufficient field trial or other budget data did not already exist, opinions of scientists and other experts were obtained using questionnaires. The economic surplus analysis provides information on projected benefits for each country, year by year. These benefits were discounted over time using a 5% discount rate, which represents the real rate of return on alternative public investments. Benefits were combined with discounted costs to obtain estimates of net present values and internal rates of return. Comparisons were made in which the new technologies to manage CMD, green mites, whiteflies and PPD were: (a) developed with MAS versus not being developed; (b) developed with MAS as compared to conventional breeding alone.

3.3 Data and assumptions for economic surplus analysis

3.3.1 Elasticities

Own-price demand and supply elasticities are needed for the economic surplus method of estimating benefits from new agricultural technologies. Own-price elasticities refer to the percent change in quantity demanded, or supplied, of a good due to a one percent change in the price of the good. Measuring own-price elasticities of a product for a particular country requires extensive data and a new study by itself. Few reliable estimates of cassava price elasticities for Sub-Saharan countries are available. As a result, we also utilize estimates for similar products and countries that are available in the literature, while considering the economic theory behind elasticity measures and utilizing income elasticities for cassava, for example, to get at the price elasticity of demand.

3.3.1.1 Demand Elasticities

Alston et al. (1995) note that if the homogeneity condition holds, then the price elasticity for a normal good is in many cases slightly higher than the income elasticity with opposite sign. The homogeneity condition states that summing the income elasticity of demand, the own-price elasticity of demand, and the cross-price elasticities, equals zero.

Nweke (2002) reported income elasticities of demand for fresh root cassava in Sub-Saharan Africa, with values of 1.24 in Nigeria and 0.95 in Uganda 0.95. There was no information provided for Ghana, but Alderman (1990) estimated the income elasticity of demand for cassava in Ghana at 0.73. But these income elasticities seem high for a staple good such as cassava. Tsegai and Kormawa (2002) used the AIDS model to estimate the cassava demand elasticity in Northern Nigeria. They found the price elasticity of demand to be - 0.46. We feel this estimate is more reasonable based on demand theory and therefore for this study, the own price elasticity of demand for cassava in Nigeria is set at - 0.46. We use the same base price elasticity for Ghana and Uganda, since country specific elasticities are not available, and provide sensitivity analyses in order to measure the variation of benefits with lower or higher price elasticities given the uncertainty about the true price elasticity of demand.

3.3.1.2 Supply Elasticities

As estimates of supply elasticities for cassava in Nigeria, Ghana and Uganda, are not available, a few examples from empirical studies elsewhere that have estimated elasticities of supply for various goods are presented. For example, Rao (1989) estimated the agricultural supply response to prices in developing countries and found crop specific acreage elasticities to vary from 0 to 0.8 in the short run and from 0.3 to 1.2 in the long run for a wide variety of crops. Peterson (1979) used cross-country data from 53 countries to estimate an appropriate long-run supply elasticity for agricultural products, which ranged from 1.27 to 1.66.

Askari and Cummins (1977) estimated supply elasticities for a number of individual crops for Chile, India, Thailand and the United States. They reported that the supply elasticity for minor crops is large as it is easier for the farmer to shift resources to other crops. Tsakok (1990) presents a list of price elasticities of supply compiled from different studies. The short-run elasticities vary from 0.1 to 0.8, while the long-run elasticities vary from 0.3 to 1.5.

Alston et al (1995) recommend the use of supply elasticity equal to 1 when data is not available. They state that in the long run all supply elasticities can be high because in the long-run most fixed factors become variable. Long run elasticities for most agricultural commodities are greater than one, while short run and intermediate elasticities are usually close to one. The further from 1, the more erroneous the results of the K formula since per hectare yield changes are divided by the elasticity of supply in the formula and elasticities are only accurate around a point. Since there are no exact supply elasticities for cassava available for Nigeria, Ghana, and Uganda, the supply elasticity for cassava for all three countries is set at 1.0.

3.3.2 Adoption

Expected adoption levels for a new variety represent one of the key variables in measuring the economic surplus generated by the new technology. The benefits from adopting the new varieties are calculated over different periods of time, depending on the technology and country. For Nigeria and Ghana, the expected time of release and pattern of adoption are similar. Varieties with mosaic disease and green mite resistance will be released in 2009, while varieties with d-PPD are expected to be released by 2015. For Uganda, varieties with mosaic disease and green mite resistance are expected to be released in 2012, and varieties with whiteflies resistance two years later. Because the new cassava varieties are in the development stage, predictions regarding their adoption were made by interviewing scientists and breeders. The level of adoption is expected to depend on the success of the new technology in providing resistance to the target stresses and providing higher yields.

Nweke (2002), based on the COSCA study data, found that approximately 60% of the villages surveyed in Nigeria had partially planted improved varieties of cassava. In Ghana, there was a delayed adoption pattern as a result of government policies neglecting this crop. Cassava in Uganda experienced increased interest both by the government and by various aid agencies as a result of the severe mosaic disease spread that devastated this crop in the 1990s. A number of cultivars are currently available for farmers to plant besides the local varieties in all three countries. For example, the IITA-developed TMS 30572 variety was the most common variety planted by farmers in Nigeria. Farmers in all the target countries have found that improved varieties were superior to local varieties in a number of ways, including yield, resistance to pests and diseases, as well as earliness of bulking or the speed of root growth. If the farmers left the roots in the ground longer than 20 months, yields between improved and local varieties tended to converge, as improved varieties would reach a yield plateau after the first few months of planting.

Johnson et al. (2006) estimated that during the period 1989-1991 Nigerian farmers in the humid zone (Southern parts of Nigeria) had a 70% adoption level, while those in the sub-humid zones only 34%. They state that only 4% of the farmers in sub-humid Ghana adopted improved varieties, while adoption was only 2% for those located in the humid zone. Data were not available for Uganda.

Scientists interviewed suggested that the maximum base adoption rate for new cassava varieties will be 40% for CMD, GM, and whiteflies resistance for all target countries. While this rate is higher for Ghana than in the previous study, the lower rate was likely due to later release of the improved varieties at that time in Ghana compared to Nigeria. Johnson et al. (2006) used data from late 1980s, but according to them widespread dissemination occurred in the 1990s although data are not readily available. Varieties with a delayed PPD are assumed to have higher adoption. The time of release of new varieties will differ for each of the countries studied, as a result of the stage in advancement of breeding. For Nigeria, the release of the new variety with resistance to green mites and the mosaic disease combined is expected in 2009. The same is expected for Ghana, while in Uganda the release of a variety with these traits is expected 3 years later. Varieties with delayed-PPD are expected to be released in 2014 for all countries. We assume an increasing adoption pattern for 6 years, a period of 4 years when adoption remains at a plateau phase, and a decline phase of 5 years. Sensitivity analysis is provided in order to estimate the potential benefits that result from different levels of adoption.

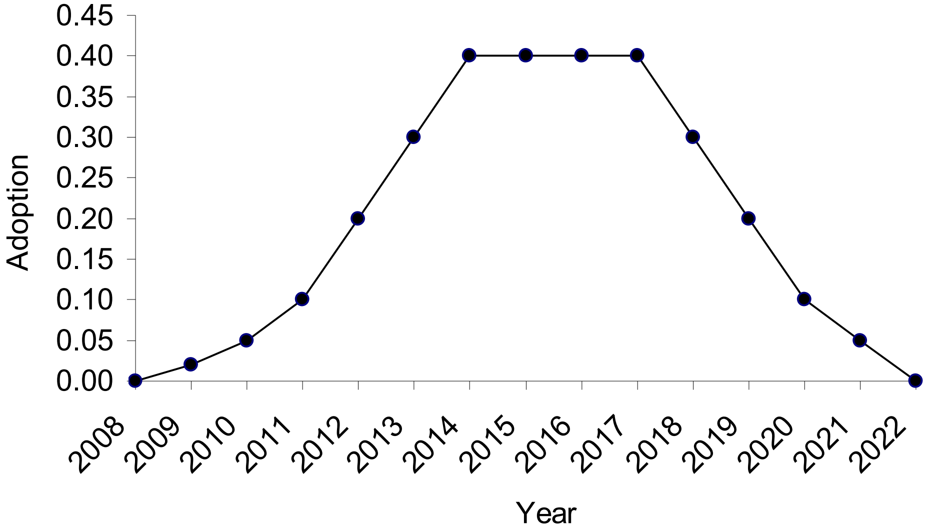

Fig. 3.3. Base model adoption rate

3.3.3. Expected Yield and Cost increases

The expected percent yield increase for improved cassava is 50% for the base scenario with CMD/GM resistance in Nigeria and Ghana. The same 50% scenario is considered for varieties with combined CMD/GM and whitefly resistance in Uganda. For varieties with delayed PPD, the expected percent yield increase is 80%, which results when we add an additional 30 percent to the 50 % yield gain from resistance to CMD, GM, and whiteflies. These estimates are based on responses from scientists who are involved in breeding the new cassava varieties as described above. Scientist trials have given much higher yields, but only in best possible environments, which include better soils, pesticides, weeding, etc. Cassava in most cases in Africa is planted on marginal soils. Even when it is not planted in marginal soils, it often lacks adequate care.

As the technology is still in the development stage, reliable farm level estimates of changes in input costs and yield from its adoption could not be obtained. However, those interviewed estimated that cassava farmers in Sub-Saharan Africa incur most of their costs from labor requirements, such as planting, weeding and harvesting. They estimated a 5% increase in requirements for labor, an adjustment needed for harvesting higher yielding varieties. Table 3.1 presents estimates of farmers input cost changes in Nigeria.

Table 3.1. Input Costs Shares for fresh cassava production per Ha in Nigeria

Input	Cost Share	Cost increase	Proportional input increase
Seeds/Cuttings	0.214	0	0
Pesticides/Herbicides	0.107	0	0
Fertilizer	0.186	0	0
Labor	0.493	0.05	0.02465
Total	**1.00**	**0.05**	**0.02465**

Source: Authors calculations based on information from the National Root Crops Research Institute (NRCRI) at Umudike, Nigeria.

Processing fresh cassava into any other form requires a much larger amount of labor, even though it does not represent part of input costs. Postharvest physiological deterioration forces farmers to consume or process fresh roots relatively quickly, or risk losing it soon after harvest. Also, many cassava varieties are “bitter” with high levels of toxic hydrocyanic acid that must be removed before consumption (Hahn, 1989). A variety of processing methods are possible, including labor-intensive methods as well as using mechanized graters. Manual methods for removing the bitter parts require most of the total labor used in processing. This processing labor exceeds the amount in production and harvesting, accounting up to 70% of the total labor required (Jeon and Halos, 1991). Therefore d-PPD not only has the potential to reduce losses due to PPD, but to save processing labor if more roots can be consumed fresh.

3.3.4 Prices, Quantities and other variables

The base variables of price and production were gathered from the FAOSTAT database, and IFPRI data and local sources were also considered. For Nigeria, the 2008 local farm level price of cassava fresh roots was estimated at \$60 per ton. The price differs from recent prices reported by FAOSTAT, which appear to report the price of gari[7] rather than that of fresh roots. For Uganda, there was no price information provided by FAOSTAT. As a result, we used information from the Ugandan government. These sources suggest an average price of about \$75 per ton of fresh cassava roots. For Ghana, we used the price provided by FAOSTAT which is about \$85 per ton. The quantities produced of cassava in these countries were obtained for the last 4 years and are presented in Table 3.2.

Table 3.2. Total Production of cassava in ('000) tons for Nigeria, Ghana and Uganda

Year	Nigeria	Ghana	Uganda
2002	34,120	9,731	5,373
2003	36,304	10,239	5,450
2004	38,845	9,739	5,500
2005	41,565	9,567	5,031

Source: FAOSTAT, 2008

Based on scientist interviews, the probability of success with MAB was set at 90% for varieties with resistance to cassava mosaic disease, green mites, and whiteflies. This probability is compared to conventional breeding, which was estimated to have a probability of success rate of 50%. For the varieties with delayed PPD, the probability of success was reduced to 67% with marker assisted breeding. For conventional breeding,

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[7] Gari is the most common processed form of cassava sold and consumed in Nigeria. The conversion rate of fresh cassava to gari in terms of weight is about 20%.

we assumed that delayed PPD cannot be introgressed into the new varieties in the foreseeable future.

Chapter 4:

Results

This chapter presents the results obtained from the economic surplus analysis of adopting marker assisted selection in breeding for improved varieties of cassava in the Sub-Saharan countries of Nigeria, Ghana and Uganda. In order to evaluate the benefits and costs of the cassava research program we project the future benefits, and subtract costs, year by year. The net present value (NPV) and the internal rate of return (IRR) are calculated, with the formulas presented in Chapter 3. The benefits of marker assisted breeding in cassava are compared to benefits of conventional breeding. We present the most probable scenarios based on the opinion of scientists and breeders, and provide sensitivity analyses with optimistic and conservative scenarios.

We first analyze the economic benefits by comparing the new MAB varieties with current varieties grown by farmers, and secondly by comparing MAB breeding with varieties developed in a conventional breeding program. More specifically, the analysis provides a set of results for the value of marker assisted breeding for resistance to cassava mosaic disease, green mites, whiteflies, and a delayed PPD. We do not consider a comparison between the MAB and CB for introgressing a delayed-PPD, because breeding for this trait with conventional phenotype-based methods cannot be achieved in the foreseeable future according to cassava breeders. Different timelines for development and release, and different target stresses, are considered for the target countries. For the breeding program in Nigeria and Ghana, resistance to the mosaic disease and green mites is considered. In Uganda, the breeding program targets the mosaic disease, green mites, and whiteflies. The postharvest physiological deterioration is a universal problem and as a result breeding for a delayed PPD is addressed for all countries considered. The base scenario data and assumptions are presented in Table 4.1.

Table 4.1 Summary of Base Data and Assumptions Used in the Economic Surplus Analysis

Variable	Nigeria	Ghana	Uganda
Production (Mt)	40,000,000	9,567,000	5,500,000
Area (Ha)	3,782,000	750,000	387,000
Price (US$/ton)	60.00	85.00	75.00
Price elasticity of demand	0.43	0.43	0.43
Price elasticity of supply	1.00	1.00	1.00
Proportionate yield change for CMD/GM/Wf resistance	0.50	0.65	0.25
Proportionate yield change for CMD/GM/Wf/d-PPD	0.80	0.80	0.50
Proportionate input cost increase	0.05	0.05	0.05
Maximum adoption (CMD/CGM/Whiteflies)	0.40	0.40	0.40
Maximum adoption (CMD/CGM/Wf/d-PPD)	0.60	0.60	0.60
Probability of success (CMD/CGM/Whiteflies)	0.90	0.90	0.90
Probability of success (CMD/CGM/Wf/d-PPD)	0.67	0.67	0.67
Depreciation (CMD/CGM/Whiteflies) (First year of)	13	13	13
Depreciation (CMD/CGM/Wf/d-PPD) (First year of)	13	13	13
Research Cost (years 1-2) (US$)	120,000	120,000	120,000
Research Cost (years 3-7) (US$)	150,000	150,000	150,000
Research Cost (years 8-11) (US$)	100,000	100,000	100,000
Research Cost (years 12-15) for d-PPD (US$)	50,000	50,000	50,000

4.1 The base scenario

For the base or ‘most likely’ scenario we employ an elasticity of demand of 0.43 in absolute value, while the elasticity of supply is set at 1. For Nigeria the increase in yield is assumed to be 50%, peak level of adoption 40%, and for calculating the NPV a 5% discount rate is used. Research and development costs are subtracted from the economic surplus benefits in the year they are incurred. Research costs include GCP costs for developing and mapping the genes of interest, and GCP and NARES costs for using the markers in breeding programs in Nigeria, Ghana and Uganda.

The costs of developing the new varieties with MAB versus conventional breeding are presented in table 4.2. These costs were obtained from the Cassava GCP proposal and rough estimates of scientists in Nigeria. Developing varieties with mosaic disease and green mites' resistance with marker assisted breeding slightly differ in costs and time from varieties with CMD, GM, and a delayed PPD within the same framework. The assumed costs of developing new varieties with resistance to CMD and GM using conventional breeding are lower than those of MAS.

Table 4.2. Research and breeding costs of developing new cassava varieties with resistance to CMD, GM and PPD (US$)

	Marker Assisted Breeding for CMD/GM			**Marker Assisted Breeding for CMD/GM/PPD**			**Conventional Breeding for CMD/GM**		
Period	**Nigeria**	**Ghana**	**Uganda**	**Nigeria**	**Ghana**	**Uganda**	**Nigeria**	**Ghana**	**Uganda**
Year 1	120,000	120,000	120,000	120,000	120,000	120,000	100,000	100,000	100,000
Year 2	120,000	120,000	120,000	120,000	120,000	120,000	100,000	100,000	100,000
Year 3	150,000	150,000	150,000	150,000	150,000	150,000	100,000	100,000	100,000
Year 4	150,000	150,000	150,000	150,000	150,000	150,000	100,000	100,000	100,000
Year 5	150,000	150,000	150,000	150,000	150,000	150,000	100,000	100,000	100,000
Year 6	150,000	150,000	150,000	150,000	150,000	150,000	100,000	100,000	100,000
Year 7	150,000	150,000	150,000	150,000	150,000	150,000	100,000	100,000	100,000
Year 8	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Year 9	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Year 10	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Year 11	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Year 12				50,000	50,000	50,000	50,000	50,000	50,000
Year 13				50,000	50,000	50,000	50,000	50,000	50,000
Year 14				50,000	50,000	50,000	50,000	50,000	50,000
Year 15				50,000	50,000	50,000	50,000	50,000	50,000

Source: Authors' calculations from GCP project proposals and interviews with scientists.

The benefits of developing varieties of cassava as compared to current varieties are substantial. Table 4.3 presents the base scenario calculation results for resistance to mosaic disease, green mites and whiteflies, respectively. The benefits are presented by country and by target trait based on the expected timing of release. The cassava mosaic disease and green mites are common for all the countries considered, and whiteflies are considered for Uganda only. The introgression of these traits into cassava is in the last stages of breeding at NARES, with their release expected as early as 2009 for Nigeria and Ghana, and 2012 for Uganda. The estimated net present value of future economic benefits, measured as the NPV of the benefits minus the research costs for the 20 years after the research began, are $1.493 billion in Nigeria, $675 million in Ghana, and $52 million in Uganda. The return on the investment, as measured by the IRR, shows a high return ranging from 48% in Uganda to 144% in Nigeria.

Table 4.3. Net benefits of MAB for resistance to mosaic disease, green mites, and whiteflies as compared to current varieties

Country	Year of Release	NPV ($000)[3]	Consumer Surplus ($000)[3]	Producer Surplus ($000)[3]	IRR[3]
Nigeria[1]	2009	$1,493,425	$1,044,353	$449,072	144.5%
Ghana[1]	2009	$675,854	$472,625	$203,229	122.4%
Uganda[2]	2012	$52,556	$36,752	$15,803	48.5%

1. Cassava mosaic disease and green mites.
2. Cassava mosaic disease, green mites, and whiteflies.
3. Net economic benefits minus research costs discounted at 5% interest rate.

Table 4.4 presents the net benefits of conventional breeding for cassava as opposed to marker assisted breeding. One difference between the two breeding methods is the time required to develop the new variety. The other variables except for the research costs used for analysis are identical, including a 5% discount rate, and adoption of new variety until complete variety decline in 13 years after release. The results of simulations show that the benefits of conventional breeding are $676 million in Nigeria, $304 million in Ghana, and $18 million in Uganda. The return on the investment ranges from 28% to 76%, depending on the country. The incremental benefits of using MAB over CB are calculated by subtracting the NPV of conventional breeding from the NPV of marker assisted breeding. The additional benefits from marker assisted breeding in cassava as opposed to conventional breeding were estimated at $817 million in Nigeria, $371 million for Ghana, and $34 million for Uganda.

Table 4.4. Benefits of CB for resistance to mosaic disease, green mites, and whiteflies, and comparison to MAB

Country	Year of Release	NPV of Conventional Breeding ($000)	IRR of Conventional Breeding	Incremental benefits of MAB over CB ($000)
Nigeria	2013	$676,033	75.6%	$817,392
Ghana	2013	$304,741	65.2%	$371,113
Uganda	2016	$18,473	27.7%	$34,083

The benefits of MAB in further pyramiding genes for delayed PPD onto varieties having resistance to the mosaic disease, green mites, and whiteflies, are presented in Table 4.5. The benefits of including d-PPD into these new varieties are substantial since pyramiding with multiple genes is not possible with conventional breeding methods for the foreseeable future. The base simulation uses similar variables as those used for the analysis of CMD, GM, and whiteflies alone. The maximum adoption level changes to 60%, while the total years of adoption after release of a new variety with all the traits is 13 years, and the other variables are identical. The benefits of adopting cassava varieties with resistance to mosaic disease, green mites, whiteflies, and has a delayed PPD amount to $3.869 billion in Nigeria, $1.108 billion in Ghana, and $338 million in Uganda. The return on investment ranges from 61% to 140%, depending on the country.

Table 4.5. Benefits of MAB for resistance to CMD/GM/Whiteflies and a delayed PPD as compared to current varieties

Country	Year of Release	Total Surplus ('000)	Consumer Surplus ('000)	Producer Surplus ('000)	IRR
Nigeria	2014	\$2,898,995	\$2,027,269	\$871,725	138.66%
Ghana	2014	\$854,623	\$597,638	\$256,984	115.44%
Uganda	2018	\$280,472	\$233,727	\$46,745	61.67%

4.2 Sensitivity Analyses

A number of sensitivity analyses were conducted that considered the changes in benefits if variables such as elasticities, yield levels, and adoption rates, were varied from the base model. These analyses were performed in order to better examine how welfare gains of the GCP program on cassava improvement change with changing basic assumptions. For example, an increase in the discount rate from 5 to 10% decreases benefits by about half (table 4.6). If on the other hand the required discount rate is lowered to 3%, the net present value of future benefits is about 50% larger than the base scenario.

Table 4.6. Benefits of MAB for resistance to CMD/GM/Whiteflies at different discount rates, the lower rate at 3%, base at 5%, and a higher rate at 10%

Country	Total Surplus at r = 3%	Total Surplus at r = 5%	Total Surplus at r = 10%
Nigeria	\$1,962,489,489	\$1,493,425	\$778,419
Ghana	\$888,398,132	\$675,854	\$352,142
Uganda	\$73,403,055	\$52,556	\$21,774

4.2.1 Timing of variety release with CB in comparison to MAB

The central variable for the incremental benefits of MAB compared to CB is the timing of release of the new varieties. The breeding process through MAB gets comparatively shorter when scientists aim at introgressing multiple traits. As the number of desirable traits to be introgressed through gene pyramiding gets larger, the probability of success with conventional breeding also decreases. Breeders refer to the impossibility of breeding for certain traits, such as d-PPD, without causing quality loss. The quality loss is related to linkage drag, or the introgression of undesirable traits together with desirable ones, risking the new variety's adoption by farmers. The benefits of MAB increase rapidly as the number of years required for developing varieties with CB increases. Table 4.7 provides the additional economic gains with MAB as the number of years increases that are required for CB to develop cassava with resistance to CMD and green mites in Nigeria and Ghana.

Table 4.7. The additional benefits of marker-assisted breeding for resistance to CMD and GM in cassava as time to release with CB increases

Years of CB as opposed to MAB	Incremental Surplus for CMD/GM resistant cassava in Nigeria ($000)	Incremental Surplus for CMD/GM resistant cassava in Ghana ($000)
3 years	$783,543	$355,828
4 years	$817,392	$371,113
5 years	$849,630	$385,670
6 years	$880,332	$399,534
7 years	$909,573	$412,737

4.2.2 Adoption Rate

This section presents estimated changes in benefits as we change the level of adoption from the base scenario. Figures 4.1 and 4.2 present the new cassava variety adoption level assumptions for the base, conservative, and optimistic scenarios based on the opinion of scientists interviewed in the respective countries. Figure 4.1 shows the adoption rate levels for cassava varieties with resistance to the mosaic disease, green mites and whiteflies. Figure 4.2 illustrates the adoption levels for new varieties of cassava with resistance to CMD, GM, whiteflies and a delayed PPD.

Fig 4.1. Adoption paths for cassava with resistance to CMD/CGM/Whiteflies

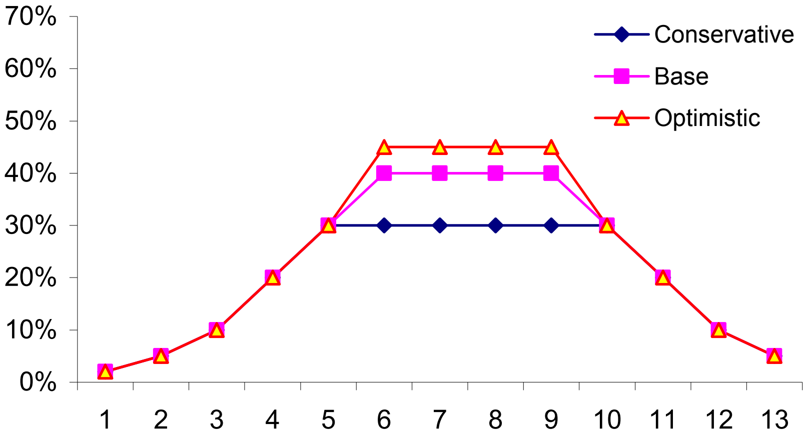
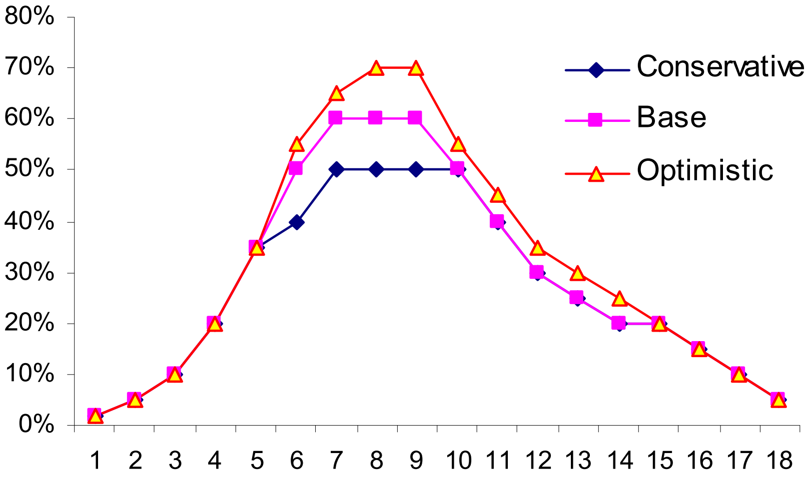


Fig 4.2. Adoption paths for cassava with resistance to CMD/GM/Whiteflies and d-PPD



The economic loss because of lower adoption compared to the base, the conservative scenario, are lower by about \$8 million in Uganda, and up to \$200 million in Nigeria, for the new varieties with resistance to CDM, GM, and whiteflies. The increase in economic benefits of a higher adoption rate, the optimistic scenario, range from about \$3 million in Uganda to almost \$50 million in Nigeria. The variation in economic gains and losses stemming from changes in adoption is even larger in the case of varieties with delayed PPD. The additional economic benefits from a change in the level of adoption for all target traits of interest are presented in Table 4.8. The large benefits related to increases in the level of adoption show the significance of national policies advancing programs related to farmer adoption of new varieties. This includes improving legislation aimed at easing the process, as well as advancing present systems of farmer information and new technology dissemination.

Table 4.8. Total economic benefits change based on the conservative, base, and optimistic scenarios of adoption rate changes

Country	Total Surplus for Conservative scenario ('000)	Total Surplus for Base scenario ('000)	Total Surplus for Optimistic scenario ('000)
Maximum adoption rate	*30%*	*40%*	*45%*
CMD/GM resistant			
Nigeria	\$1,285,596	\$1,493,425	\$1,598,282
Ghana	\$581,045	\$675,854	\$723,822
CMD/GM/Whiteflies			
Uganda	\$42,328	\$49,142	\$52,556
Delayed-PPD			
Nigeria	\$2,640,001	\$2,898,995	\$3,219,902
Ghana	\$785,810	\$854,623	\$939,900
Uganda	\$256,746	\$280,473	\$309,887

4.2.3 Yield Changes

Yield improvements represent one of most important factors affecting net changes in benefits. A sensitivity analysis of yield increase impacts of new varieties of cassava is provided in Table 4.9. The percent yield changes are not uniform for the different target countries or target traits. This is because of different current mean yields for the target countries that result in different percentage yield increases. The opinions of scientists surveyed are used for setting the base, conservative and optimistic yield changes for each country.

In Ghana, the base yield change of CMD/GM resistant cassava from current varieties is assumed to be 65%. Changing the average yield increase to 40% based on the conservative scenario reduces the net economic benefits by almost $280 million. For the same country and target traits, increasing percent mean yield to 80%, increases the net economic gains by about $170 million. In Uganda, the assumed percentage yield changes are in the lower end for cassava varieties with CMD, GM, and whiteflies resistance. Compared to the base scenario, the analysis shows economic losses of $26 million for the conservative rates, or gains of $52 million for the optimistic scenario. For the varieties with delayed PPD in Nigeria, the conservative option of yield changes shows economic losses of almost $1 billion, compared with the base assumption. In the same comparative basis, economic gains with the optimistic scenario are almost $500 million.

Table 4.9. Economic benefits for various percent yield increase assumptions for Nigeria, Ghana, and Uganda with MAB

% Yield Increase, Trait, and Country	Total Surplus for Conservative scenario ('000)	Total Surplus for Base scenario ('000)	Total Surplus for Optimistic scenario ('000)
CMD/GM resistant			
Nigeria	*30%*	*50%*	*60%*
	$829,467	$1,493,425	$1,828,048
Ghana	*40%*	*65%*	*80%*
	$396,319	$675,854	$847,727
CMD/GM/Whiteflies			
Uganda	*10%*	*15%*	*25%*
	$26,487	$52,556	$104,833
CMD/GM /Delayed-PPD			
Nigeria	*60%*	*80%*	*90%*
	$2,209,641	$2,898,995	$3,246,930
Ghana	*40%*	*65%*	*80%*
	$484,658	$854,623	$1,078,930
Uganda	*20%*	*40%*	*50%*
	$97,545	$223,240	$303,522

4.2.4. Elasticities

Sensitivity analysis considered changes in supply elasticities and in own-price elasticities of demand. The impacts of changes in the elasticity of demand are not as large on the net welfare effects as the changes in other variables discussed above (Table 4.10). This is expected as welfare changes are only slightly affected by changes in demand elasticities, while welfare changes can be much larger in magnitude if the own-price elasticity of supply is varied. The elasticity of demand in absolute values is 0.43 for the base, 0.2 for the conservative, and 0.53 for the optimistic scenario.

Table 4.10. Economic benefits under conservative, base, and optimistic scenarios of own-price demand elasticities

Demand Elasticity, Trait, and Country	Total Surplus for Conservative scenario ('000)	Total Surplus for Base scenario ('000)	Total Surplus for Optimistic scenario ('000)
Elasticity of Demand	*0.2*	*0.43*	*0.53*
CMD/GM resistant			
Nigeria	$1,480,424	$1,493,425	$1,497,859
Ghana	$668,086	$675,854	$678,503
CMD/GM/Whiteflies			
Uganda	$52,437	$52,556	$52,596
Delayed-PPD			
Nigeria	$2,857,985	$2,898,995	$2,912,980
Ghana	$844,734	$854,623	$857,996
Uganda	$470,672	$481,101	$484,657

For the cassava varieties with mosaic disease and green mites' resistance, the results show that a lower elasticity of demand in Nigeria would cause an economic loss of approximately $13 million, compared to the base scenario. If the optimistic scenario elasticity is considered, the net welfare gains would increase by about $4 million. In Uganda, for the new varieties with delayed PPD, the net benefits would be reduced by about $4 million if assume the conservative own-price demand elasticity instead of the base. The economic benefits of increasing the elasticity of demand from the base to the optimistic assumption are a little more than $1 million for Uganda.

Table 4.11 presents the sensitivity analysis of changes in the supply elasticities, with the elasticity of demand held at base level of 0.43. The variation in net benefits as we change the elasticity of supply is much larger than the same effect of demand elasticities. The base elasticity of supply is equal to 1, while the conservative scenario supply elasticity is set at 1.2, and optimistic scenario at 0.8. The analysis shows that higher supply elasticities reduce net benefits by a large amount. For example, the difference in net benefits between the conservative and base scenarios of supply elasticities for varieties with CMD and GM resistance is over $250 million in Nigeria, $120 million in Ghana, and about $12 million in Uganda. On the other hand, having a lower elasticity of supply increases total net benefits by a substantial amount as well. For new cassava varieties with resistance to mosaic disease and green mites, that also have delayed PPD, the benefits increase by $300 million in Nigeria, over $200 million in Ghana, and $120 million in Uganda.

Table 4.11. Economic benefits under conservative, base, and optimistic scenarios of own-price supply elasticities

Supply Elasticity, Trait, and Country	**Total Surplus for Conservative scenario ('000)**	**Total Surplus for Base scenario ('000)**	**Total Surplus for Optimistic scenario ('000)**
Supply Elasticities	1.2	1	0.8
CMD/GM resistant			
Nigeria	$1,223,372	$1,493,426	$1,900,274
Ghana	$555,688	$675,855	$857,100
CMD/GM/Whiteflies			
Uganda	$40,010	$52,556	$71,409
Delayed-PPD			
Nigeria	$2,376,213	$2,898,995	$3,688,575
Ghana	$699,044	$854,623	$1,089,350
Uganda	$345,249	$423,323	$541,631

Chapter 5:

Conclusions and Discussion

This chapter presents a summary of results and a discussion of the development of cassava varieties with traits of interest. The economic surplus analysis was utilized to measure the societal benefits of marker assisted breeding (MAB) for developing improved varieties of cassava with resistance to cassava mosaic disease (CMD), cassava green mites (GM), whiteflies, and delayed postharvest deterioration in Nigeria, Ghana and Uganda. Diseases and insects such as CMD, GM, whiteflies and PPD cause substantial losses to farmers and significantly limit the potential of cassava as a food crop in Africa. Obtaining resistance to targeted insects and diseases can be difficult with conventional breeding alone, especially when breeders aim at trait pyramiding. Other undesirable traits may be transferred to the new varieties, often limiting the desired resistance and bringing in other undesirable traits. Marker assisted breeding is more precise as it allows for the isolation of specific genes, which are identified on molecular maps that can be accessed by scientists and breeders worldwide.

Marker assisted breeding is estimated to save from 2 to 4 years in the breeding process, but could potentially save as many as 7 years, compared to conventional breeding which requires at least a 15-year breeding process to variety release. Varieties with CMD and GM resistance are expected to be released as early as 2009 in Nigeria, with a technology lifespan of 13 years until complete depreciation. The net benefits of MAB for cassava varieties with mosaic disease, green mites, and whiteflies total almost \$1.5 billion in Nigeria, \$675 million in Ghana, and \$52 million in Uganda. Total benefits for varieties including delayed PPD amount to $2,898 billion in Nigeria, $854 million in Ghana, and $280 million in Uganda. Benefits using conventional breeding are less than half those of MAB in most cases. The incremental benefits of MAB over CB for CMD, GM, and whiteflies resistance are $817 million in Nigeria, $371 million in Ghana, and $34 million in Uganda. The incremental benefits result mainly from earlier timing of release of new varieties. The results show that in any case, introgressing resistance to mosaic disease, green mites, whiteflies, and PPD is economically beneficial for the target countries both with MAB and conventional breeding techniques.

5.1 Limitations and Future Research

One important limitation of this study is the lack of detailed research cost data for developing new varieties of cassava at the international centers as well as in each respective country. Time requirements for developing new varieties are estimated based on the experience of the scientists interviewed. Scientist questionnaires and project proposals were used to estimate the costs of developing new cassava varieties. The results show that the benefits outweigh the costs of developing the new cassava varieties, even though the research costs are larger with MAB and are not identified with precision. Brennan and Martin (2007) note that in order to fully assess the impact of new technologies in agriculture, it is important to know the cost structure and the key components of the costs of the different stages of wheat breeding programs. They state that unless the research costs are known, the full impact of the new technologies on costs cannot be totally understood.

The results of this study are based on rough estimates from scientists regarding percent yield change, adoption, etc. Future studies could involve ex-post methods to measure the benefits of the Cassava GCP program after the new varieties are released. Issues that directly affect variety adoption include current regulations and the system used for new variety dissemination through extension services. For example, in Nigeria the National Seed System multiplies and disseminates seedlings to farmers. The system is often very slow, involving local Agricultural Development Programs (ADPs), and that slowness limits the adoption levels of new released varieties. Future studies could aim at answering what are the benefits of improving the dissemination system. Another issue relates to the limitation of land where seedlings are multiplied by the Nigerian government. For a large country like Nigeria, seed multiplication often takes several years because of the need for a large number of seedlings. Another avenue of future research may aim at estimating the determinants of cassava variety adoption in Nigeria, Ghana and Uganda. This estimation could help policy makers to determine characteristics affecting adoption, including but not limited to education, ethnic group, geographical location, etc. This information could be useful to policy makers in order to target specific areas or characteristics with the most impact.

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Appendix 1:
Cassava Scientist Questionnaire

Date: _______________

We are conducting an analysis to project the economic impacts of developing low cost technologies for pyramiding useful genes from wild relatives into elite progenitors of cassava. We will be projecting the economic impacts of using molecular-assisted selection to incorporate green mite and CMD resistance in Cassava varieties in Nigeria, Ghana, and Uganda. We will also be evaluating economic impacts of using molecular-assisted selection to incorporate white fly resistance in cassava in those countries and resistance to post harvest physiological deterioration (PPD). We would appreciate your assistance in providing responses to a set of questions to help us with this task. Please respond for as many of the three countries as you feel comfortable.

A. Respondent

Name: ____
Organization: ____
Position: ____
Specialization: ____
Years of work experience with cassava: _________________________________

B. Technology questions

1. What is the current stage of the technology development? We understand from earlier comments that this past year there were three entries with the green mite/CMD resistance at 8 locations in national cassava regional trials in Nigeria (2nd year of testing). Only one could be placed in on-farm trials in 13 states because of a national limitation. Another 11 genotypes ready to go, of which some will go into regional trials next year, but you plan to disseminate all 11 in 3 states (in east, west, and central Nigeria) for testing with 3000 farmers. Is this information correct? Material with resistance to white fly or PPD have not yet been received for testing in Africa. Please update with any other information about the current stage of the technology testing in Nigeria, or in Ghana or Uganda.

____
____
____
____
____
____
____
____
____
____

2. What are the names of the existing cassava variety(s) in each country in which the green mite and CMD resistance genes are being incorporated?

Nigeria	Ghana	Uganda
1.		
2.		
3.		

3. We need to know how many years it will take to complete the technology development (such as incorporating CMD/green mite resistance) using MAS versus using conventional breeding alone? The following table reflects our current understanding. Please review the table and correct either the steps or the years listed.

Activity	Year (Conventional Breeding)	Year (With MAS Breeding)
Female x Male	Year 0	Year 0
F1	Year 1	Year 1
Clone evaluation	Year 2	Year 2
Preliminary yield trials	Year 3	**Skip**
Advanced yield trials	Year 4	**Skip**
Uniform yield trials	Years 5-6	Years 3-4
Regional trials	Years 7-8	Years 5-6
On farm trials	Year 9	Year 7
Variety release	Year 10	Year 8
Multiplication*	Years 11-15	Years 9-13
Total Number of Years	15	13

*Note: Multiplication conventionally takes 5 years, but it could be cut to 2 years if managed by breeder with additional resources.

4. We would appreciate your rough estimates of the costs in developing the CMD/green mite resistance technologies (labor costs, input costs, etc for each step if possible). We realize some of these costs may have been incurred at CIAT in Colombia and so if necessary just fill in the costs from the time the material is received in Nigeria.

Activity	Conventional Breeding	MAS Breeding
Female x Male		
F1		
Clone evaluation		
Preliminary yield trials		
Advanced yield trials		
Uniform yield trials		
Regional trials		
On farm trials		
Variety release		
Multiplication		
Total Costs:		

C. Questions on crop losses, expected yield and cost changes

5. We have collected data on existing cassava production and yield per hectare by state in each country from FAO and IFPRI. However, any suggestions about other local sources for recent production data would also be appreciated ________________________________

____

6. It would be very helpful to know the percent of the cassava growing areas that are affected by the various pests if they differ by region within the countries. What is your best estimate of the percent of the cassava production area in each region in the country that is seriously affected by the targeted insects/diseases? (We assume PPD affects all areas).

Country/region	**% of Cassava area affected by CMD/white flies**	**% of Cassava area affected by green mites**	**% of Cassava area affected by Horn-flies**
Nigeria			
Eastern			
Central			
Western			
Uganda			
Southern			
Central			
Northern			
Ghana			
Southern			
Central			

7. We understand that the best new lines with CMD/green mite resistance yielded 30-40 tons per hectare in regional yield trials in Nigeria, and that varieties currently being planted by farmers typically yield in the range of 10-20 tons per hectare. Are these estimates accurate? Yes_____ No _____. If not, what are your best estimates of the yields for the new varieties ________ and the old ones? _____________

8. What do you expect will be the lowest, most likely, and highest expected percent yield change per hectare for farmers who adopt new CMD/green mite resistant varieties?

Country	Yield Gain (%) / ha		
	Lowest	Most Likely	Highest
Nigeria			
Ghana			
Uganda			
Brazil			

9. What do you expect will be the lowest, most likely, and highest % yield change per hectare for farmers who adopt new varieties that are resistant to both CMD/green mites **and whiteflies**?

Country	Yield Gain (%) / ha		
	Lowest	Most Likely	Highest
Nigeria			
Ghana			
Uganda			
Brazil			

10. Do you expect the costs of cassava production per hectare to differ for the new varieties as compared to the ones currently being used by farmers? Yes____ No____. If yes, please fill in the table below. It asks for the percent of total variable costs currently represented by each input, and your estimate of the percent change in cost per hectare, if any, for each of the inputs if CMD/green mite resistant varieties are adopted in Nigeria. It also asks for the percent change in costs (compared to current varieties) if CMD/green mite and white fly resistant varieties are adopted.

Input	Share of Total Cost (%)	Most like change			Change in cost with CMD/GM resistant variety (%)	Change in cost with CMD/GM and white fly resistant variety (%)
		Decrease	No change	Increase		
Seed (Planting material)						
Labor						
Fertilizer						
Pesticide						
Total	100%					

11. Do expect the % cost shares and changes indicated above to differ for Ghana? Yes___ No____. If yes, please fill in the table below.

Input	Share of Total Cost (%)	Most like change			Change in cost with CMD/GM resistant variety (%)	Change in cost with CMD/GM and white fly resistant variety (%)
		Decrease	No change	Increase		
Seed (Planting material)						
Labor						
Fertilizer						
Pesticide						
Total	100%					

12. Do expect the % cost shares and changes indicated above to differ for Uganda? Yes___ No____. If yes, please fill in the table below.

Input	Share of Total Cost (%)	Most like change			Change in cost with CMD/GM resistant variety (%)	Change in cost with CMD/GM and white fly resistant variety (%)
		Decrease	No change	Increase		
Seed (Planting material)						
Labor						
Fertilizer						
Pesticide						
Total	100%					

(Any additional budget info you may have for cassava production would be appreciated).

13. What is your best estimate of the percent of cassava production that is lost to postharvest physiological deterioration (PPD) during the first two weeks after it is harvested in: Nigeria_____________, Ghana________, Uganda ___________?

D. Questions on technology adoption

14. In what year do you expect varietal release for cassava with CMB/green mite resistance and for cassava with CMD/green mite and white fly resistance?

Country	**Year of variety release for CMD/green mite resistant cassava**	**Year of variety release for CMD/green mite/whitefly resistant cassava**
Nigeria		
Ghana		
Uganda		

15. What is the maximum expected level of adoption by farmers (% of cassava area), and how many years after it is released do you expect to see maximum adoption?

Country	**What is the expected maximum (%) of variety adoption?**		**How many years after variety release will maximum adoption occur?**	
	CMD/green mite resistance	CMD/GM/white fly resistance	CMD/GM resistance	CMD/GM/white fly resistance
Nigeria				
Ghana				
Uganda				