An ex ante economic evaluation of genetically modified cassava in South Africa

by

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Dedication

To my husband Charles and son Blessings

"Thus far the Lord has taken us"

Ebenezer

Declaration

I declare that this thesis I hereby submit for the degree of MSc Agric (Agricultural Economics) at the University of Pretoria is entirely my own work and has not been submitted anywhere else for the award of a degree or otherwise.

Any errors in thinking and omissions are entirely my own responsibility.

Signed: ………………………

Name: Charity Ruramai Mudombi

Date: February 2010

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ABSTRACT

The main objective of this study is to evaluate the economic potential and opportunities for introducing Genetically Modified (GM) cassava that is Cassava Mosaic Virus (CMV) resistant and has improved starch properties in South Africa. The level of cassava production in South Africa is limited and thus a study on a new technology for this crop may seem strange. However, with innovations like the CMV resistance trait or amylose free cassava starch, cassava production in South Africa can possibly become more viable and relatively more profitable than competing crops such as maize and potatoes.

Various ex ante economic methods and approaches to assessing economic impacts exist in the subject literature: the partial budget approach, cost benefit analysis, consumer and producer or economic surplus approach and the computable general equilibrium (CGE) or simulation model. For the purpose of this study and due to available data, a simple gross margin analysis was applied to analyse the economic profitability of genetically modified cassava in South Africa in comparison to maize and potato. Due to data limitations, this study relies on a synthesis between secondary information from various studies in other African countries and interviews with experts. The information collected was used to assess the potential for genetically modified cassava in South Africa. Secondary information and interviews with experts were used to provide more insights and information relating to the possible opportunities, constraints, performance of the genetically modified events, and production practices for cassava and other competing crops like maize and potato in the country.

The gross margin analysis results show that cassava production is not profitable at farm level for both dryland and irrigation scenarios. However, processing cassava into starch results in higher returns from the higher starch output and quality compared to potato and maize. The starch from cassava has many industrial applications. The scenario analysis for GM cassava and infected cassava at 10%, 20%, 30% and 40% expected yield loss showed that the CMV resistant and amylose free GM cassava provides additional benefits due to its better quality and higher starch yields compared to infected varieties. The higher quality starch yields a higher profit making it even more profitable to produce cassava for starch.

The results of interviews with subject experts show that cassava production and utilisation has lagged behind other crops in South Africa and the crop is sparingly and informally traded. An analysis of market constraints showed that there is a strong consumer taste preference for maize and other cereals dominating the starch market. Other factors that have contributed to the lagging behind of cassava in South Africa and other African countries are the post colonial government policies that favoured maize over cassava.

Cassava has a number of important traits that present a competitive advantage for cassava as a commercial crop for farmers compared to other crops such as maize and potato. For example, cassava can be grown under difficult environmental conditions and has a wide range of applications ranging from food products to industrial starches. Cassava can be grown as a monoculture crop, unlike maize and potato which require rotation. In addition, the special characteristics of cassava starch present an important alternative to maize, wheat, rice and potato. Cassava flour and starch have unique properties which make them ideal for many applications in the food, textile and paper industries where flour and starch from other crops hold a quasi monopoly. For example, among starch producing plants, cassava has been considered as the highest yield producer (25 to 40 percent higher than potato, rice and maize) and as the most efficient (the highest) converter of solar energy to carbohydrate per unit area.

However, despite these advantages, cassava has remained a neglected crop in South African agricultural research and development activities compared to cereals. However, the increasing demand for starch based applications in the food industry and industrial sector and the fact that the industry is searching for a cheaper substitute for cereals present an impressive market growth potential for cassava starch. For example, industries including the paper industry, food industry and textile industry are the main buyers of cassava starch in South Africa.

The results from interview discussions show that there are some concerns and questions related to the introduction of GM cassava in South Africa. One of the main concerns was that empirical studies in South Africa have shown that the occurrence of cassava mosaic virus in the country is very low; it has an approximate 2 percent incidence rate. As a result, large scale producers have been able to control CMV through good management practices, natural selection and chemical control. Also, bureaucracy and lack of transparency in the South African genetically modified organism (GMO) regulatory system, especially regarding socio-economic issues consumer perception on GM cassava, may result in an extended delay before contained field trials are conducted in the country. It has also become clear that the two proposed GM events are still relatively far from being commercialisable. Furthermore, the current availability of mutant varieties of conventional cassava varieties that can produce better quality starch with a very low amylose content provide an important alternative to GM cassava. The utilisation of the former tends to be less time consuming and less expensive compared to GM cassava.

It is difficult to perform a socio-economic assessment before confined laboratory tests or field trials have been conducted. Further development of the potential product would supply crucial information that is needed for an ex ante socio-economic study. It is clear that this study was conducted far too early as GM technologies are not yet remotely close to being ready for commercialisation. Many basic studies still need to be conducted, including field trials. The South African GMO Act and regulations do not clearly stipulate when a socio-economic study should be conducted, but it is clear that the worth of a study conducted before any confined field trials had been performed would be questionable.

Key words: cassava, genetically modified, South Africa, starch, ex ante, gross margin

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ACRONYMS AND ABBREVIATIONS

ACMV	African Cassava Mosaic Virus
ARC	South African Agriculture Research Council
BCR	Benefit Cost Ratio
BFAP	Bureau for Food and Agricultural Policy
CBA	Cost Benefit Analysis
CBSD	Cassava Brown Streak Disease
CBSV	Cassava Brown Streak Virus
CGE	Computable General Equilibrium
CMD	Cassava Mosaic Disease
CMG	Cassava Mosaic Geminivirus
CMV	Cassava Mosaic Virus
CS	Consumer Surplus
CSM	Cassava Starch Manufacturing Company
CV	Compensation Variation
EACMMV	East African Cassava Mosaic Malawi Virus
EACMV	East African Cassava Mosaic Virus
EACMV-CM	East African Cassava Mosaic Virus-Cameroon
EACMV-UG	East African Cassava Mosaic Virus-Uganda
EACMZV	East African Cassava Mosaic Zanzibar Virus
EV	Equivalent Variation
FAO	Food and Agriculture Organisation of the United Nations
GM	Genetically Modified
GMO	Genetically Modified Organism
IRR	Internal Rate of Return
NPV	Net Present Value
PS	Producer Surplus
RMRDC	Raw Materials Research and Development Council
SACMV	South African Cassava Mosaic Virus
TS	Total Surplus

CHAPTER 1

Introduction

1.1 Introduction and background

Cassava (*Manihot esculenta* Crantz) is a tropical shrub perennial crop and is mainly grown for its carbohydrate rich tuberous roots (Mabasa, 2007; Ceballos *et al.*, 2004). Cassava is mostly produced for human consumption either fresh or in various processed forms and the remainder is processed as animal feed and industrial products. An estimated 600 million people consume cassava worldwide (Food and Agriculture Organisation of the United Nations (FAO), 2006). The crop is not only a valuable direct source of food in many parts of Africa, but the starch obtained from the tuber also has wide industrial applications. Cassava roots can be processed into a wide variety of products for food and industrial uses such as starch, flour, alcohol and glucose. The leaves, which are rich in proteins, vitamin C and other nutrients, are consumed in some communities to supplement the low protein content of the roots (Mabasa, 2007).

Cassava yields in Africa are very low (estimated at 8.9t/ha) as compared to other cassava producing regions (Asia and Latin America), although the former is the largest producer of the crop. However, under optimal conditions cassava can produce up to 80t/ha of tubers in a 12 month culture period (Legg and Thresh, 2003). Various factors are responsible for the severely low yields in Africa which include lack of irrigation and fertiliser, and virus diseases like Cassava Mosaic Virus (CMV). The virus diseases caused by begomoviruses are one of the most important constraints to cassava production in sub-Saharan Africa. These viruses cause Cassava Mosaic Disease (CMD) and result in enormous yield losses severely affecting farmers. Other important virus diseases are the cassava brown streak disease (CBSD) and bacterial blight (caused by *Xanthomonas axonopodis* pv. *manihotis*) (Mabasa, 2007).

Cassava is the fourth main source for starch production in the world, after maize, wheat and potato. Starch is used as a raw material for a wide range of food products and industrial goods, including paper, cardboard, textiles, plywood, glue and alcohol. The production and use of cassava starch presents an important alternative to maize, wheat, rice and potato. Cassava flour and starch have unique properties which make them ideal for many applications in the food, textile and paper industries which are currently dominated by flour and starch from other crops such as maize, potatoes and wheat (Bokanga, 1995). For example, among starch producing plants, cassava has been considered as the highest producer of starch (25 to 40 percent higher than rice and maize) and as the most efficient (the highest) converter of solar energy to carbohydrate per unit area (Sudarmonowati, Hartari and Sukmarini, 2006).

Despite the socio-economic importance of cassava, growth rates for production and utilisation have lagged behind other crops in South Africa. In South Africa, as in many developing countries, cassava is traded sparingly and informally. The shortage of established marketing channels and market information has been among the main factors constraining trade in cassava. The weak market is due to several factors. One of these factors is a taste preference for maize and other cereals resulting in cassava remaining a minor crop in South Africa and other developing countries. Another factor is that over the years there has been limited research into and development of cassava to keep it a competitive crop in the agricultural and commercial worlds compared to cereal crops like maize, potatoes and wheat. In addition, the cassava crop is usually grown and utilised by the poor and this has contributed to its relegation to a lower status by both private and public research (Hershey *et al.*, 2000).

The level of cassava production in South Africa is limited and thus a study on a new technology for this crop may seem strange. The reason for the study to be done in South Africa is that South Africa is the only country in Africa that has functioning biosafety regulations and has a history of growing genetically modified (GM) crops like Bt cotton and maize. It should be noted that this research and the resulting contained use and field trials could potentially contribute to the development of better cassava varieties for Africa. Herein lies the reason for the study: with new GM technologies cassava production in South Africa can become more viable and valuable than other competing crops like maize and potatoes as the new technology addresses the vital production limitation of the cassava mosaic virus and delivers a more valuable high quality starch product (amylose free cassava starch). For the genetically modified cassava to gain the institutional support for commercialisation it is necessary to carry out an ex ante assessment of the economic potential and opportunities of the intervention. This study reviews the economic potential and opportunities for introducing GM cassava that is CMV resistant and has improved starch properties (amylose free) in South Africa.

1.2 Genetically modified cassava

A genetically modified crop's genetic material has been altered in a manner that does not occur naturally through multiplication or natural selection. This can be done through the removal of a specific gene, switching a gene on or off or inserting a specific gene, (Arendse, undated). The genetic engineering of crops provides new opportunities for improving crop productivity and solving agricultural problems such as pests and diseases, abiotic stresses and nutritional limitations of staple foods and commercial crops.

The production of GM crops is increasing worldwide (FAO, 2003a). In South Africa, GM maize, cotton and soy beans were approved for commercial use (Arendse, undated). This study focuses on GM cassava that is CMV resistant and is amylose free (has improved starch properties) in South Africa. GM cassava that is CMV resistant helps to reduce losses caused by the virus. GM cassava is amylose free and has better starch properties than other crops, an important characteristic in the starch industry. The absence of amylose in GM cassava means that the starch gelatinises easily, yielding clear pastes that will not gel, a characteristic known as clarity, and this improves the quality of cassava starch. It is important for use as a stabiliser and thickener in food products and as an emulsifier for salad dressings. It should be noted that the lower amylose content can also improve the quality of pasta (Joblings, 2003).

In addition, amylose free starch has an improved paste stability (freeze/thaw stability) which is the ability of a product to maintain its composition and integrity after repeated cycles of freezing and ambient temperature levels. This is expected to be an important characteristic for application in both the food and paper manufacturing industries. However, for most applications chemical cross-linking and stabilisation is needed for native starches to be more stable than amylose free starches. From a consumer perspective, with consumers increasingly more concerned about the use of chemicals in what they eat, and from an environmental view it would be advantageous if freeze–thaw stability could be engineered without the use of chemical treatments which are expensive and also environmentally unfriendly (Joblings, 2003).

1.3 Problem statement

Cassava was introduced from Mozambique into South Africa during the major tribal movements of the mid1800s and subsequently spread into Mpumalanga (formerly eastern Transvaal), Swaziland and northern KwaZulu-Natal (Mabasa, 2007). However, cassava cultivation has remained confined to these areas. A combination of environmental limitations and a taste preference for maize means that cassava has remained a minor crop in South Africa where it is predominantly grown by small scale farmers close to the borders to Mozambique. Average cassava field sizes range from 0.05-0.25ha and the crop is grown as a secondary staple food and/or for sale locally. Like in many other African countries, cassava yields in South Africa are consistently low, ranging from 7.8t/ha to 15t/ha and this is mainly due to cassava pests and diseases as well as lack of investment in inputs (Mabasa, 2007). Cassava has a potential yield of 30-45t/ha on a commercial basis (Legg and Thresh, 2003; South African Agriculture Research Council, 2009) compared to other competing crops like potato which had a commercial yield of around 34t/ha in 2007 (International year of the potato, 2009).

Over the years a number of studies have shown that CMV is the most damaging pest constraint to cassava production in Africa. CMD caused by the CMV results in enormous yield losses severely affecting farmers. In addition, poor agricultural practices and various other diseases caused by bacteria, fungi and nematodes (Hillocks, 2002) contribute to low cassava yield levels although they are considered of minor importance (Mabasa, 2007). Genetically modified mosaic virus resistant and amylose free cassava offers great potential for improving the competitiveness of cassava utilisation for industrial food and starch production. Also, amylose free starch from GM cassava has an excellent stability and clarity that does not need further chemical modification for industrial uses (Salehuzzaman *et al.*, 1993). This reduces the cost of starch production for industrial uses and avoids the use of chemicals which might be environmentally unfriendly such as expoxides (propyleneoxide, ethlyne oxide) and acids (Reamakers *et al.*, 2005).

Currently, the main commercial production and utilisation of cassava in South Africa is the production of industrial starch products by a private company called the Cassava Starch Manufacturing Company (CSM) with a factory situated at Dendron in the Limpopo province (Casey, 2008; Mabasa, 2007). However, developments in the starch industry show that there is a growing interest in South Africa to produce cassava for industrial purposes. For example, with the rising production and interest in bio-fuels in the world market there is a demand for more starch producing crops because of the fluctuating prices of petroleum. In South Africa, for instance, there is an increasing demand for ethanol ever since leaded fuels were banned in 2006. Lead was used to raise the octane levels in fuel, but it was environmentally unfriendly. Ethanol has replaced lead and it is environmentally friendly (Alexander, 2005). Ethanol can be used as an alternative source of energy because it is environmentally safe and ethanol gel stoves have gained popularity in informal settlements where there is no grid electricity and in camping as an alternative to arguably more dangerous gas and paraffin.

In the food industry consumers are opting for a gluten free diet, especially in baby foods which contain a minimum of allergens; cassava starch is used as one of the alternatives to maize and wheat starch (Casey, 2008). For instance, Enterprise Foods uses cassava starch as a binding in sausages. These sausages last six times longer than those that use maize and wheat starch, contributing to lower production costs for the company (Casey, 2008). Another example is Lucky Star who also uses cassava starch as a thickening in the sauces in tinned fish. There are also developments to produce cassava beer by the South African Breweries (now known as SABMiller) in Angola in order to substitute expensive barley and hops. The development of clear cassava beer is expected to halve the price of beer across Africa, creating a bigger market for cassava (The Retail Exchange, 2009). The increasing demand for starch based applications in the food industry and industrial sector and these industries' search for a cheaper starch present an impressive market growth potential for cassava production. For example, an emerging market for cassava starch is to produce biodegradable products such as packaging material and kitchenware. Discarded plastic products have the potential to cause environmental pollution, and as a result discarding these products places a burden on municipalities' waste management systems (International Trade Centre 2003).

The increased demand for starch presents opportunities for cassava production and thus for improved cassava production technologies. Increasing cassava utilisation by the food and feed industries provides a stimulus for increased cassava production in South Africa. Therefore, it is important to evaluate the potential for introducing a GM cassava that is CMV resistant and produces amylose free starch cultivar in South Africa. The expected benefits from the production of GM cassava are twofold: (a) reduced crop yield losses as a result of the control of CMV with a virus resistant cultivar and (b) an amylose free and better quality starch cultivar. However although GM cassava has important traits it is also important to mention that amylose free cassava may not favourable for other confectionary purposes especially for the people who suffer from cancer of the colon because they may require the presence of amylose in their diet..

No ex ante assessment of the potential of GM cassava has been done in South Africa to answer the above question. This study fills this gap by evaluating the potential economic opportunities of introducing genetically modified cassava in South Africa. The ex ante evaluation of the potential impacts of introducing genetically modified cassava is of importance in informing policy discussion on the promotion and adoption of GM cassava for commercial, industrial and subsistence food uses. Since South Africa is the only African country with a history of GM crop reviews and a perceived favourable regulatory environment, an ex ante assessment of the economic impacts of GM cassava can enrich the discussion on the approval decision and also supply useful background information on a lesser known, yet remarkable, crop.

1.4 Objectives of the study

The main objective of the study is to evaluate the economic potential for introducing genetically modified cassava that is CMV resistant and produces amylose free starch in South Africa. As stipulated in the South African biosafety regulations, an ex ante socioeconomic impact assessment of transgenic crops is required before it is released commercially. This study aims to provide the background and analytical information needed to inform the regulatory decision making process.

The objectives of the study are to:

- review the economic potential and opportunities for introducing GM cassava that is CMV resistant and yields better quality starch (amylose free starch) in South Africa,
- evaluate the economic profitability of introducing genetically modified cassava that is mosaic virus resistant and yields better quality starch (amylose free starch) compared to local varieties and other competing crops like maize and potatoes, and
- identify perceived limitations to increased production and utilisation of cassava in South Africa.

1.5 Limitations to study

This study has certain limitations that should be borne in mind. First, there is lack of data on the South African cassava sub-sector because the study done was based on request on a topic with limited information in South Africa. For example, organisations that deal with crops like the Institute for Industrial Crops at ARC have limited information on cassava production in South Africa, especially in the smallholder sector due to the fact that cassava production is not popular compared to maize and potato. It is difficult to perform a socio-economic assessment before confined laboratory tests or field trials have been conducted. Further development of the potential product would supply crucial information that is needed for an ex ante socio-economic study. It is clear that this study was conducted far too early as GM technologies are not yet remotely close to being ready for commercialisation. Many basic studies still need to be conducted, including field trials. The South African GMO Act and regulations do not clearly stipulate when a socio-economic study should be conducted, but it is clear that the worth of a study conducted before any confined field trials had been performed would be questionable

1.6 Hypotheses of the study

The hypothesis for this study is:

- Genetically modified cassava that is mosaic virus resistant resulting in higher yields, and yields better quality starch (amylose free starch) is an economically viable alternative compared to local varieties of cassava and other starch producing crops.
- Consumer perceptions and institutional factors are some of the important constraints to the widespread production, processing and utilisation of GM cassava in South Africa.

1.7 Approach and methods of the study

Various ex ante economic methods and approaches to assessing economic impacts exist in the subject literature: the partial budget approach, cost benefit analysis, consumer and producer or economic surplus approach and the computable general equilibrium (CGE) or simulation model. For the purpose of this study and due to available data, a simple gross margin analysis was applied to analyse the economic profitability of genetically modified cassava in South Africa in comparison to maize and potato. Due to data limitations, this study relies on a synthesis between secondary information from various studies in other African countries and interviews with experts. The information collected was used to assess the potential for genetically modified cassava in South Africa. Secondary information and interviews with experts were used to provide more insights and information relating to the possible opportunities, constraints, performance of the genetically modified events, and production practices for cassava and other competing crops like maize and potato in the country.

1.8 Organisation of the thesis

The following chapter presents a discussion of background information regarding cassava in order to provide a better understanding of the various economic issues of the crop. Chapter 3 presents a discussion of various methods that are used in ex ante studies, a review of the empirical application of these methods in previous studies, and the analytical approach of this study. Chapter 4 discusses cassava utilisation and opportunities for commercial cassava starch applications in South Africa. The impacts of cassava mosaic disease and opportunities for genetically modified cassava that is resistant to cassava mosaic virus in South Africa are presented in Chapter 5. The chapter also presents a comparison of the cassava gross margin to those of maize and potatoes showing the benefits of growing cassava for processing. Conclusions and recommendations are presented in Chapter 6

CHAPTER 2

Constraints and economic potential of Cassava in Southern Africa

2.1 Introduction

This chapter presents a discussion of background information regarding cassava in order to provide a better understanding of the various economic issues related to the crop. The chapter discusses the historical background of the crop in Africa, its consumption, nutritional value and uses and the production value chain. In addition, regarding the main goals of the study, this chapter presents an overview assessment of the potential production and utilisation constraints for cassava, the economic importance of cassava in southern Africa, and a brief discussion of the traits that make cassava an important food and commercial crop for farmers.

2.2 The cassava crop

Cassava (*Manihot esculenta* Crantz) is a tropical shrub perennial crop and is mainly grown for its carbohydrate rich tuberous roots (Mabasa, 2007; Ceballos, Iglesias and Dixon, 2004). Cassava belongs to the family *Euphorbiceae* that includes other commercially important plants such as the castor bean (*Ricinus communis* L.) and rubber (*Havea bransiliensis* L.) (Mabasa, 2007). Cassava and some 90 other species make up the genus *Manihot* and it is the only widely cultivated member of this genus.

Cassava is the fourth main source for starch production in the world, after maize, wheat and potato (FAO, 2006). Cassava is utilised for human consumption either as fresh roots or in various processed forms and the remainder is processed into animal feed and industrial products. An estimated 600 million people consume cassava worldwide (FAO, 2006). The crop is not only a valuable source of carbohydrates in many parts of Africa, but the starch obtained from the tuber also has many industrial applications in the paper, textile, pharmaceutical and food processing industry (Rey, 2007). Cassava roots can be processed into a wide range of food products and industrial goods, including paper, cardboard, textiles, plywood, glue and alcohol. The leaves which are rich in proteins, vitamin C and other nutrients are consumed in some communities to supplement the low protein content of the roots (Mabasa, 2007).

Cassava is one of the most important food crops in Africa and is widely grown in Latin America and Asia. It has become very important as a food security crop and for poverty alleviation in Africa since its introduction from Latin America into Africa by Portuguese traders in the late sixteenth century (Fauquet and Fargette, 1990). It was introduced from Brazil into the west coast of Africa and later to East Africa through Madagascar and Zanzibar. Most of the spread of cassava away from the coastal areas and riverside trading posts in Africa took place during the twentieth century due to colonial powers encouraging cassava production as a reserve against famine (Hillocks, 2002.) However, post colonial governments' increased attention to maize in terms of funding and research efforts as well as a taste preference for maize led to a decline in cassava cultivation in the 1960s (Haggblade and Zulu, 2003).

Most African countries south of the Sahara are now growing cassava and the crop has since become the dominant staple food in some countries. Today, cassava is grown on an estimated 17 million hectares in 34 African countries (FAOSTAT, 2009). Africa produces 54 percent of the world's cassava and the bulk of the produced cassava in Africa is for human consumption (Mabasa, 2007). Maize is the dominant staple food in most eastern and southern African countries, but cassava is very important in Nigeria, Mozambique, Tanzania, Uganda and Burundi as a reserve against famine (Mabasa, 2007).

Cassava is suited to warm humid lowland tropics and can be cultivated in most areas where the mean annual temperature exceeds 20 Degrees Celsius with an annual rainfall that varies between 500mm and 8000mm (Pounti-Kaerlas, 1998). Although cassava is relatively drought tolerant it grows best where the rainfall exceeds 1200mm per year and can be cultivated on almost all soil types, requiring only limited agronomic and pest management practices (Mabasa, 2007). In addition, cassava roots can be left in the ground for a long time before harvesting giving poor farmers a useful security against famine. Compared to other staple foods like maize, rice and wheat, cassava is the least expensive to cultivate and its characteristics make it ideal for small scale farmers in many tropical countries who have limited access to expensive agricultural inputs and storage facilities (Mabasa, 2007).

Figure 2.1 below shows a picture of the cassava plant. The cassava shrub has tall, thin, straight stems and, when fully grown, attains an average height of one to two meters although some cultivars may reach a height of four meters (Raw Materials Research and Development Council (RMRDC), 2004; International Trade Centre, 2003). The stem is often marked along its entire length by numerous leaf scars indicating the position from where its palmate leaves of five or six leaflets have dropped off (RMRDC, 2004).

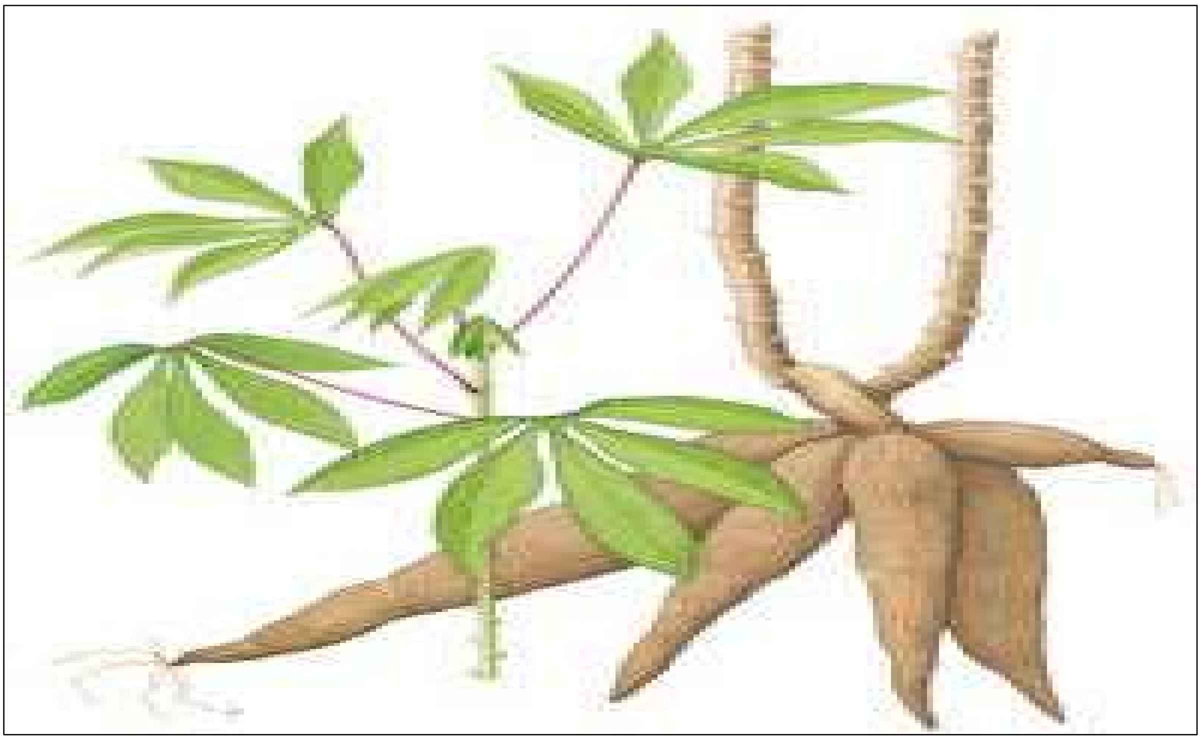

Figure 2.1: Cassava plant
Source: RMRDC (2004)

Depending on the variety and age of the plant, the fibrous roots may grow up to 15cm in diameter and 120cm in length and weigh between one and eight kilograms (RMRDC, 2004; International Trade Centre 2003). Some of these fibrous roots undergo the process of tubulisation (swelling due to the cambium tissue) leading to an increase in the diameters of the roots. Tubulisation also corresponds to the storage functions of the root tuber for different food materials, produced by the plant, particularly starch. Therefore, the roots are a very good source of food materials for animal and human consumption (RMRDC, 2004).

Although the leaves of the plant have been found to be rich in proteins, vitamins and other nutrients, the tuberous root (or root tuber) is the major source of cassava food, usually starch. The roots of a 1 to 1.5 year old cassava plant have a starch content ranging from 20 to 32 percent, which is higher compared to other starch food crops (International Trade Centre, 2003). Its utilisation largely depends on the level of production and the quality of starch in the roots (RMRDC, 2004).

Both cassava roots and leaves are suitable for human consumption. The roots are an important source of carbohydrates and the leaves contain proteins and minerals (Kilimo Trust, 2007). Cassava cultivars are classified as sweet or bitter depending on their cyanide content. Bitter varieties are especially suited to industrial and feed purposes, while sweet varieties are generally preferred if the root is for human consumption (Kilimo Trust, 2007). The former is not safe for human consumption unless properly treated.

2.3 Cassava production value chain

Goldstuck (2006) summarised the activities adopted in cultivating cassava as follows: select a site, prepare the land, prepare planting materials, plant, apply fertiliser, remove weeds, harvest, dry roots, grind roots, and store. The cultivation stage of cassava's value chain, as outlined above, is relatively simple and these activities can be performed on a farm by a small scale farmer or at a village or local level.

Secondary non-agricultural activities in the cassava supply chain, such as marketing, processing and packaging products are performed by fewer, large scale units. Goldstuck (2006) reported that the unique feature of cassava's supply chain in southern Africa is its hour-glass shape that provides opportunities for numerous small scale farmers to be involved in cultivating, harvesting and in rudimentary process activities compared to other activities along the value chain. The supply chain “begins with small-scale production units, followed by small-scale processing units for the drying and/or milling of cassava” (South African Agriculture Research Council (ARC), 2007).

The structure of cassava’s supply chain provides potential contact points for small scale farmers to participate in a larger market. Therefore, the growth and development of cassava product markets present potential benefits for a large number of resource-poor farmers located on poor lands and for local processing units. However, reaping the pro-poor benefits associated with cultivating cassava hinges on developing and distributing simple micro technology for farmers to process cassava into a transportable product that feeds into industrialists’ downstream processing activities (Goldstuck, 2006).

2.4 The nutritional value of cassava

The starchy roots are a valuable source of energy and can be boiled or processed in different ways for human consumption. Roots can also be used for obtaining native or fermented starches, dried chips, meal or pellets for animal feed (Ceballos *et al.*, 2004). Native starches contain a mixture of two types of polymers namely, amylopectin and amylose. Amylopectin consists of large, highly-branched molecules, making up the bulk of the starch found in plants (GMO Compass, 2009). Amylose consists of long, chain-like molecules (GMO Compass, 2009). Amylopectin is water soluble and has a high bonding capacity which makes it suitable for use in the manufacturing of adhesives, paste and lubricants. Amylose and amylopectin must be separated or modified by chemical, physical, or enzymatic processes because amylose is not readily digested. Other relevant traits for the roots are dry matter content, percentage of protein and carotenoid contents. Cassava roots are low in protein content with an average of about 2 to 3 percent protein (dry weight basis) (Ceballos *et al.*, 2004).

A typical cassava root is composed of at least 60 percent moisture, 26 percent starch, 2 percent fibre, 1 percent protein and 3 percent other elements (Table 2.1) . Table 2.2 presents the average nutrient composition (per 100gm) edible portion of cassava compared to that of some staple food crops found in Africa. The chemical composition of cassava varies in different parts of the plant, and according to variety, location, age, method of analysis, and environmental conditions (Okigbo, 1980). The high water content makes the root bulky and highly perishable and this requires processing to be done within 48 hours of harvesting. Processing helps remove naturally occurring toxins found in the root which enhances its value and reduces the weight of the product thereby facilitating transportation to markets. This is also an important step in reducing post-harvest losses arising from the breakage of roots and extending the product's shelf-life (Kilimo Trust, 2007).

Table 2.1: Nutritional value of cassava

Component	Root	Leaves
Moisture (%)	62.8	74.8
Energy (kg/100g)	580	-
Protein (%)	0.53	5.1
Starch (%)	31.0-35.0	-
Sugar (%)	0.83	-
Dietary fibre (%)	1.40	-
Ash (%)	0.84	2.7
Minerals (mg/100g)		
Ca	20	350
P	46	56
Mg	30	-
K	320	-
S	6.4	-
Fe	0.24	218
Vitamins (mg/100g)		
Vitamin A	Trace	3
Thiamine	0.05	0.2
Riboflavin	0.04	0.3
Nicotinic acid	0.6	1.5
Vitamin C	15.0	200

Adapted from: Bicol (2009)

Cassava stems are the most important source of planting material to propagate the crop. Cassava foliage is not widely exported outside the main production areas because of its high perishability in spite of its high nutritive value, although the consumption of leaves by human populations is relatively common in certain countries of Africa and Asia (Ceballos *et al.*, 2004). Foliage is also used for feeding animals. Crude protein content in leaves range between 20 and 25 percent dry weight (Babu and Chatterjee, 1999; Buitrago, 1990), and can be as high as 30 percent (Buitrago, 1990) making it ideal for animal feed.

Table 2.2: Average nutrient composition (per 100gm edible portion) of cassava compared to that of some staple food crops found in Africa

	Unit	Potatoes	Sweet potatoes	Fresh cassava	Yams	Taro	Maize	Sorghum	Cowpea
Food energy	calories	82	117	146	105	104	363	335	340
Water	gm	78	70	62.5	72.4	72.5	12	12	10.0
Carbohydrates	gm	18.9	27.3	34.7	24.1	24.2	71	71	60.0
Protein	gm	2.0	1.3	1.2	2.4	1.9	10.0	10.4	22.0
Fat	gm	0.1	0.4	0.3	0.2	0.2	4.5	3.4	1.5
Calcium	mg	8	34	33	22	23	12	32	90
Iron	mg	0.7	1.0	0.7	0.8	1.1	2.5	4.5	5.0
Vitamin A	I.U.	Trace	500	Trace	Trace	Trace	Trace	Trace	20
Thiamine, B1	mg	0.10	0.10	0.06	0.09	0.15	0.35	0.50	0,9
Riboflavin, B2	mg	0.03	0.05	0.03	0.03	0.03	0.13	0.12	0.15
Niacin	mg	1.4	0.6	0.06	0.5	0.9	2.0	3.5	17.0
Vitamin C	mg	10	23	36	10	5	0	0	Trace

Source: Okigbo (1980)

Cassava can yield about 40t/ha which is about 3 to 4 times higher than the yield of maize. Cassava is poor in proteins (1 to 2 percent) compared to maize and cowpea with 10 and 22 percent proteins respectively. The amino acid profile of the cassava root is very low in some essential amino acids, particularly lysine, methionine, and tryptophan. Cassava is reasonably rich in calcium and vitamin C, but the thiamine, riboflavin, and niacin contents are not significant (Okigbo, 1980).

2.5 Constraints to cassava production and utilisation

2.5.1 Cassava production constraints

Cassava yields in Africa are very low (estimated at 8.9t/ha) as compared to other cassava producing regions (Asia and Latin America) although Africa is the largest producer of the crop. Under optimal conditions cassava can produce up to 80t/ha of tubers in a 12 month culture period (Legg and Thresh, 2003).

Various factors are responsible for the severely low cassava yields in Africa and the most important constraints include a lack of fertilisers since cassava is a subsistence crop, drought and viral diseases which have proved difficult to remedy through chemical treatment (Rey, 2007). The cassava mosaic viruses cause cassava mosaic disease and result in enormous yield losses which severely affect farmers (Rey, 2007). Other important virus diseases are the cassava brown streak disease and bacterial blight (caused by *Xanthomonas axonopodis* pv. *manihotis*) (Mabasa, 2007).

Cassava mosaic disease is now considered the most damaging pest or disease constraint to cassava production in Africa and Asia, while CBSD is most prevalent in the coastal regions of East Africa with the greatest effects in northern Mozambique (Thresh, 2001). In addition, poor agricultural practices and various other diseases caused by bacteria, fungi and nematodes (Hillocks, 2002) contribute to low cassava yield levels although they are considered of minor importance (Mabasa, 2007).

2.5.2 Cassava utilisation constraints

A major constraint to the expansion of the market for fresh, dried, chilled and frozen cassava is the lack of product recognition by non-cassava producing countries. Market development is essential to stimulate new demand. The perishable nature of the crop is another obstacle to market expansion. The development of a dehydrated or frozen french-fry product would help to remove storability problems. While cassava does not have close substitutes or complements, it has limited consumers, as populations in new markets become integrated into their own staples (FAO, 2000). This market phenomenon can clearly be observed in South Africa where maize production and consumption dominate the agricultural market.

In many developing countries, cassava is sparingly traded in an informal manner. The shortage of established marketing channels and poor infrastructure and market information have been among the main factors constraining trade in cassava. Transporting the roots is a big problem because they are bulky and highly perishable. Therefore, trade could be promoted through the development of local processing, the establishment of market information systems and the promotion of niche-markets for special products (FAO, 2000). The future of trade in cassava products will largely depend on institutional factors, particularly the policies implemented by major importers.

Despite remaining an “orphan crop” cassava’s importance has grown steadily over the past 50 years (FAO, 2000). Smallholder farmers who grow cassava in Africa have little incentive to produce more than what is needed for their subsistence requirements as cassava presents many post-harvest and marketing challenges. However, surplus crop can be used as organic fertiliser. Cassava would have potential to be a profitable crop, but lack of investment in the improvement of its quality and industrial processing as well as inadequate post-harvest facilities makes it less competitive than maize, rice and potatoes.

Over a decade both the cassava snack food and cassava flour markets have shown limited potential for exporters of cassava to expand these markets. Cassava exporters can promote the virtues of their product, but will probably have to rely on the major food manufacturers, food technologists and consumer preferences to determine if there are growing market opportunities for processed cassava as a human food (FAO, 2000).

2.6 Economic importance of cassava in southern Africa

The Portuguese introduced cassava into Mozambique in the seventeenth century where it was adopted as a food crop by Tsonga tribesman. The Tsonga later spread cassava westwards into Mpumalanga (formerly eastern Transvaal), and Swaziland and southwards into northern KwaZulu-Natal (Woodward, Allemann and O' Reagan, 1997). Cassava cultivation in South Africa is believed to have come with the major tribal movements of the 1830s and 1860s (Trench and Martin, 1985). Cassava was introduced in Malawi and Zimbabwe via Portuguese trading routes from Mozambique, while in Zambia it was introduced via the Congo basin (Haggblade and Zulu, 2003).

Cassava is extensively grown in Zambia, Malawi and Zimbabwe. In Mozambique cassava is grown mainly in the northern provinces of Nampula, Zambezia and Cabo Delgado as the main staple food (Thresh, 2001). Furthermore, cassava and sweet potato are being introduced as a government initiative in drought prone areas throughout Mozambique (Equator Initiative, 2003).

In South Africa, cassava is grown by a limited number of subsistence farmers as a secondary staple food mainly in the provinces of Mpumalanga, KwaZulu-Natal and Limpopo (Woodward *et al.*, 1997). Most of these farmers live close to the borders of Mozambique and tend to have a link to Mozambique. In recent years, the only commercial cultivation of cassava in South Africa has been done by a company called CSM whose main business is to process cassava into industrial starch in their factory close to Dendron in the Limpopo Province. Recently, commercial cassava farms have been established in Mpumalanga (Barberton) mainly for plant propagation (Casey, 2008). Plans for a second factory in Swaziland are at an advanced stage (Casey, 2008). The main consumers of Mpumalanga starch are the food, textile, paper, corrugated cardboard and mining industries. The company owns about 2000 hectares of cassava fields and they used to outsource additional raw materials by contracting in small scale farmers. However, they have stopped outsourcing to small farmers owing to reasons such as the failure of small farmers to keep planting material clean and low quality cassava (Mabasa, 2007; Casey, 2008).

The chief constraint for large-scale cassava production in southern Africa has been the lack of a market. Post colonial government policies, in many southern African countries, favoured the production of maize over cassava and this ultimately influenced consumption patterns and consumer preferences. This has resulted in maize being grown in areas environmentally not suited to it where cassava would perform far better in terms of reliable yields (Mabasa, 2007). However, droughts and unsustainably high maize subsidies have lead to changes in government policies since the early 1990s. For example, efforts to promote cultivation of cassava in Zambia and Malawi as a subsistence crop have paid off and cassava production in these countries has grown by between 6 percent and 8 percent per year respectively, which is among the fastest growth rates in Africa and the world (Haggblade and Zulu, 2003).

The success stories from Zambia and Malawi present an opportunity for such initiatives in South Africa where cassava could replace maize in drought-prone areas and marginal soils without interfering with land most suited to maize production. Cassava can play a useful role in improving the livelihoods of smallholder farmers in southern Africa, by providing an opportunity for farmers, to produce a relatively low input, yet resilient cash crop.

2.7 Important cassava traits as a food and commercial crop for farmers

Cassava has a number of unique characteristics that furnish it with a competitive advantage over other crops. These unique traits appeal to both smallholder and commercial farmers (Goldstuck, 2006; Rey, 2007; Okigbo, 1980):

- Cassava can be grown in difficult environmental conditions characterised by low or extreme rainfall and infertile, poor, sandy soil.
- Cassava is a simple crop to maintain as it has no definite maturation point and thus can be left in the ground from 7 months to 2 years after planting and then harvested as needed. Consequently it can recover from certain pest damage and diseases.
- Cassava provides an opportunity to improve rural dwellers' income by opening up marginal lands under cultivation.

- Cassava can be grown as a monoculture crop, unlike maize and potatoes which require rotation by law.
- Cassava is easily propagated by stem cuttings.
- Cassava is a labour intensive crop to harvest, and as a result it will provide employment to unskilled labourers in rural areas.
- Cassava is a highly perishable, bulky crop and thus must be processed before it is transported, which opens up numerous opportunities for small scale farmers and rural entrepreneurs to get involved in processing and value adding (vertical integration).
- Cassava has a wide range of applications ranging from food products to industrial starches. The processes required to produce these products vary in complexity which gives different parties the flexibility to pursue markets that suit their skill and resource base.
- Cassava starch has a much lower amylose content (17%) than starches from other sources and compares well with the specifically developed waxy starches of maize.
- When produced in the correct manner, cassava is a relatively high yielder of biomass and an excellent source of calories. Cassava produces more carbohydrates per unit area than is provided by any other staple food. Its yield could reach 80t/ha, adding up to 250,000 calories per hectare per day.

Despite these advantages, cassava has remained a neglected crop in South African agricultural research and development activities compared to cereals like maize and wheat. At present, most glucose is produced from maize starch, but if cassava could be introduced successfully, it could become the preferred source of raw material as a result of its higher yield per unit area.

2.8 Summary

This chapter described background information about cassava in order to provide a better understanding of the various economic issues facing the crop. Cassava is one of the most important food crops in Africa. The crop is not only a valuable source of food in many parts of Africa, but the starch obtained from the cassava tuber also has widespread industrial applications such as starch, flour, alcohol, glucose and others. The cultivation stage of cassava’s value chain, as outlined by Goldstuck (2006) is relatively simple and these activities can be performed on a farm by a small scale farmer or at a village or local level. The cassava supply chain provides potential contact points for small scale farmers to participate in a larger market. Therefore, the growth and development of cassava product markets presents potential benefits for a large number of resource-poor farmers. This is beneficial to farmers as they can grow and process cassava on their farm thereby increasing their income by selling semi processed products.

Various factors are responsible for the severely low yields in Africa and the most important constraints are virus diseases. Cassava mosaic disease is now considered the most damaging pest or disease constraint to cassava production in Africa. In addition, poor agricultural practices, lack of fertiliser and various other diseases caused by bacteria, fungi and nematodes contribute to low cassava yield levels. Another major constraint for large-scale cassava production and utilisation in southern Africa has been the consumer taste preference for cereals and research support programmes that favoured maize and other cereals over cassava.

Despite low levels of production and utilisation in South Africa, cassava has a number of important traits that present a competitive advantage for cassava as a commercial crop for farmers that is comparable to other crops such as maize and potatoes. For example, cassava can be grown in difficult environmental conditions and has a wide range of applications ranging from food products to industrial starches. However, cassava has remained a neglected crop in South African agricultural research and development activities compared to cereals. These observations justify the need to assess the potential opportunities for cassava production and utilisation in the country.

CHAPTER 3

A literature review on ex ante economic approaches and analysis of genetically modified crops

3.1 Introduction

This chapter discusses the various approaches and methods that could be used to analyse ex ante economic impacts of biotechnology crops. In addition, the chapter reviews empirical studies of these methods in ex ante analyses of GM crops. This section is included to illustrate how the approaches have been applied in different ex ante studies from various literature sources and their conclusions. Ex ante economic impacts of genetically modified crops have been estimated using a number of approaches: the partial budget approach, Cost Benefit Analysis (CBA), the economic surplus model or consumer and producer surplus approach and the Computable General Equilibrium (CGE) or simulation model. The summary concludes with a discussion of the approach chosen to implement the empirical analysis and the expected contributions of this study.

3.2 Why ex ante socio-economic studies?

A socio-economic assessment conducted before the potential release, importation, or adoption of a Genetically Modified Organism (GMO) in order to ascertain the impact on the economy and society, is known as an ex *ante* assessment whereas a study conducted after approval and adoption is known as an *ex post* study. An *ex ante* assessment generally makes use of experiment or field trial data supplied by scientists and developers of the product in order to predict the performance of a new product. In the Cartagena Protocol on Biosafety, allowance is made for including a socio-economic assessment in biosafety regulatory approval processes and decision making for GM products. To get a biosafety approval, an assessment of socio-economic considerations is likely to be done before the GM product reaches the commercialisation approval processes. Socio-economic assessments may help to reduce the possibility of selecting GM products that do not have a market potential (Flack-Zepeda, 2009).

In an *ex post* study, impact estimations are based on data collected from different sectors and stakeholders who have experienced the impact of a new product. This is a different form of calculating the costs and benefits of the investment in new technological research after the improved varieties have been developed and adopted by farmers. In addition, they help assess the magnitude of research payoffs and farm and community level constraints to the future adoption of new technologies. Ex ante assessments help identify social and economic constraints which can inform decision makers about complementary investments that have the potential to ensure the success of new technologies (Lusts and Smale, 2003). Also, ex ante studies are done to help researchers select the "best bet" varieties in the case of genetically modified varieties.

3.3 Approaches to measuring ex ante economic impacts of genetically modified crops

Ex ante economic impacts of genetically modified crops have been estimated using a number of approaches: the partial budget approach, cost benefit analysis, the economic surplus model or consumer and producer surplus approach and the computable general equilibrium or simulation model. Each of these approaches is discussed in more detail below.

3.3.1 Partial budget approach

The partial budget approach compares the costs and returns of alternative production scenarios and evaluation of economic effects of minor adjustments to changes in resources (Dalsted and Gutierrez, 2001). This approach estimates changes in profits or losses, measures changes in income and returns of limited resources, provides limited assessment of risk, and suggests a range of prices or costs at which a technology becomes profitable. The method only includes budget components that are expected to change with the adoption of the new technology. The required variables included in the partial budget will vary according to what is expected to change. The basic data requirements are input and output quantities, input prices, productivity levels of alternative technologies and output prices. (Babu and Rhoe, 2003)

3.3.1.1 Limitations of partial budgeting and gross margin analysis

The partial budgeting approach is useful, but as its name suggests, does not take the total or aggregate impact of technology introduction into account. Partial budgets and gross margins are not a measure of the profit of a new technology, as they do not include overhead costs such as depreciation and interest to fixed factors of production and returns to management. The farmer incurs these overhead costs regardless of whether or not any new crop technology is produced. In addition, comparisons of gross margins should be interpreted in relation to fixed costs and overall investment levels. Some new crop technologies require greater fixed costs and annual investments than others. Therefore, a change in new crop technology could result in the lowering of fixed costs for one new crop technology that is greater than an increase in gross margin for another new crop technology (Anandajaysekeram, Van Rooyen and Libenberg, 2004; Matala *et al.*, 1998; Makeham and Malcolm, 1986).

Partial budget and gross margin analysis usually do not consider potential social and environmental impacts that might result from the introduction and adoption of new technology. Potential environmental impacts (both positive and negative) from each new economic crop technology can be identified and economic values can be attached as a way of incorporating social and environmental benefits and costs into the gross margin analysis. However, due to the difficulties encountered in measuring these potential environmental costs and benefits, they are usually eliminated from financial gross margin analysis. Most economic decisions involve multiple criteria (e.g. financial, environmental and social) for making economic choices on the introduction of new technologies. Therefore, the decision to introduce a new technology must take potential environmental impacts into account as well as the measurable economic costs and benefits of that undertaking (Anandajaysekeram *et al.*, 2004).

Partial budget and gross margin analysis is not an analytical optimisation tool and does not show the optimal way to implement GM technology or how profitable the introduction will be. It only makes comparisons between financial returns from different production scenarios, that is, net returns to variable costs (Anandajaysekeram *et al.*, 2004).

3.3.1.2 Advantages of the partial budget approach

The advantage of this approach is that it allows for a comparative analysis of costs and returns of alternative production methods or technologies, and evaluation of economic effects of minor adjustments and changes in fixed resources (Dalsted and Gutierrez, 2001). The analysis from partial budgeting helps in decision making by providing insights into the impact of the new technology to producers. Partial budgeting makes use of gross margin analysis, a financial analytical approach that determines the profitability of production (Matala *et al.*, 1998). It is the difference between the total gross income and the total variable costs of an enterprise.The other advantages of gross margin analysis is that it allows comparisons to be made between different enterprises and farm units. In addition, financial analysis is important for planning purposes in each enterprise and the farm as a whole. They can also be used to make forecasts on the operation of a new technology as part of the planning process. In doing an ex ante assessment comparing different technologies, different scenarios for the adoption of a new technology are compared to the “current state of affairs” or the counter factual.

3.3.2 Cost benefit analysis (CBA)

The cost benefit analysis methodology represents a framework of project benefits in which costs are identified, quantified, valued and compared to a range of optimality criteria on an ex ante basis (Anandajaysekeram *et al.*, 2004). It focuses on direct benefits and costs by applying the economic shadow pricing method. The analysis accounts for multiplier effects, secondary effects and linkages. The cost benefit approach considers measurable gains and losses to determine the best course of action. It is useful for estimating the current and future impacts resulting from a potential technology introduction. The data required for the estimation of benefits include the expected total area affected by the technology, the expected percentage change in output per unit of input, net reduction in price discount, reduction in pesticide cost, net decrease in storage loss, expected price per tonne of the genetically modified crop and price per unit of crop, change in price of output and change in input cost (Gittinger, 1995). In the case of the introduction of GM technology, a comparison may be done on the additional cost caused by the increase in the price of the new seed with the benefits that will result due to yield increase and cutting down on the price of pesticides. There are several stages in a CBA, namely defining the project, identifying impacts, calculating a monetary valuation, discounting, weighting and sensitivity analysis (Hanley and Spash, 1995). At the stage of calculating a monetary valuation the CBA uses discounted measures of project worth tools such as the Net Present Value (NPV) and Benefit Cost Ratio (BCR). These measures are discussed in more detail below.

3.3.2.1 Discounted measures of project worth

Net present value (NPV)

Net present value is the present worth of the income stream generated by an investment. In other words, it is the present worth of the incremental net benefit or incremental cash flow stream (Gittinger, 1995). Mathematically, it is calculated by the formula:

$$NPV=\sum_{t=1}^{t=n}\frac{B_t - C_t}{(1+i)^t}$$

where B_t and C_t are benefits and costs in a given year, t, i is the interest (discount) rate, and n is the number of years. Benefits or costs without monetary values are usually left out or estimated. The formal selection criterion for the NPV measure of project worth is to accept all independent projects with a zero or greater NPV when discounted at the opportunity cost of capital (the interest rate). The problem of the NPV measure is that the selection criterion cannot be applied unless there is a relatively satisfactory estimate of the opportunity cost of capital. In addition, because NPV is an absolute, non-relative measure, it is not possible to rank alternative independent projects. The NPV method also assumes a time schedule, something that is difficult to guess at in an ex ante assessment.

Benefit cost ratio (BCR)

The BCR is the present worth of the benefit stream divided by the present worth of the cost stream:

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

The formal selection criterion for the BCR measure of project worth is to accept all independent projects with a BCR of 1 or greater when the cost and benefit streams are discounted at the opportunity cost of capital. BCR can be used directly to note how much the cost could rise without making the project economically unattractive (Gittinger, 1995). The NPV and BRC are ways that investment viability can be assessed, but that is not applicable to a socio-economic assessment of GM crops.

3.3.2.2 Limitations of cost benefit analysis

The limitations of the cost benefit approach are listed below:

- Benefits are often more difficult to quantify than costs. On the contrary, many of these benefits are non-economic, and economic analysis seeks to translate these benefits into financial terms which is often problematic thus biasing the analysis.
- Cost benefit analysis often includes subjective assumptions regarding non-economic values. Therefore, this method contains a large margin for error because economists often

have to make assumptions regarding the financial value of non-economic values, whether they are costs or benefits.

- In some cases cost benefit analysis may be used where the fundamental legal authority may not allow direct consideration of economic cost, or makes safety a priority regardless of costs. Particularly where there is the risk of a hazardous materials or public harm the relevant statutory authority may require regulations based on addressing public harm without an explicit consideration of economic cost (UNEP, 2009).

3.3.2.3 Advantages of cost benefit analysis

Cost benefit analysis helps put a monetary value on the viability of a project or technology which can move the project forward to a point where a decision can be made whether to go ahead with it or not. When a decision is made, the awareness of various aspects of the project increase and new issues may arise. Roles and responsibilities may also begin to be allocated for the progress of the project. The approach also helps to identify expensive mistakes that may be prevented as unexpected costs are brought to light. If a cost benefit analysis is done well it can identify the point at which a project will break even, or when the payback period will begin.

3.3.3 The economic surplus model or the consumer and producer surplus approach

The economic surplus approach uses a partial equilibrium single market analysis to determine how benefits are distributed among producers and consumers. The benefit experienced by each group will depend on the behaviour of producers and consumers (Babu and Rhoe, 2003) and the way the new technology impacts on them. The approach has four main considerations:

- the cost adjustment from one production system to another,
- the comparison between cost and direct returns of alternative production practices,
- the output response of producers, and
- the overall costs and benefits from an industry-wide technology adoption (Anandajaysekeram *et al.*, 2004).

The welfare effects of agricultural technologies have been widely evaluated using the economic surplus model. Alston, Norton and Pardey (1995) provide extensive evidence supporting the use of the economic surplus approach for evaluating the potential impacts of agricultural technologies. The advantage of this model is that it can be modified to take into account effects like research induced quality changes, market distorting policies and any other economic distortions (in other words, externalities) (Hareau, 2002).

The economic surplus model measures the Producer Surplus (PS) and Consumer Surplus (CS) generated in a transaction. The producer surplus measures the return to quasi fixed factors of production to producers from selling the good at the equilibrium price and consumer surplus reflects the willingness of a consumer to pay more for a good than the market price (Alston *et al.*, 1995; Hareau, 2002).

Figure 3.1 below is a graph representing the partial equilibrium analysis using producer and consumer surplus. From the graph, area PAB represents the producer surplus that measures the total revenue less the cost of producing quantity Q of the good. Consumer surplus is presented by area PAC that can be interpreted as the total surplus received by the consumer less the cost of buying quantity Q of the good at price P. PS and CS measure the welfare of producers and consumers respectively. Changes in PS, CS or Total Surplus (TS) can be measured as a change in these areas.

The impacts of technological change as a result of research in agriculture can be to increase yields or reduce the costs of production once the new technology is adopted (Alston *et al.*, 1995; Hareau, 2002). In the case of a yield increasing new technology, the producer sells more of the good in the market and, if the demand is outward sloping, the price decreases. With a cost reducing technology the producer produces the same quantity as before, but at a lower cost. The overall impact of technological change is a reduction in the cost of producing one 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 (Hareau, 2002). These changes cause the supply curve to shift resulting in new equilibrium levels between prices and quantities being realised in the market. In either case the new equilibrium is achieved at a lower price and higher quantity.

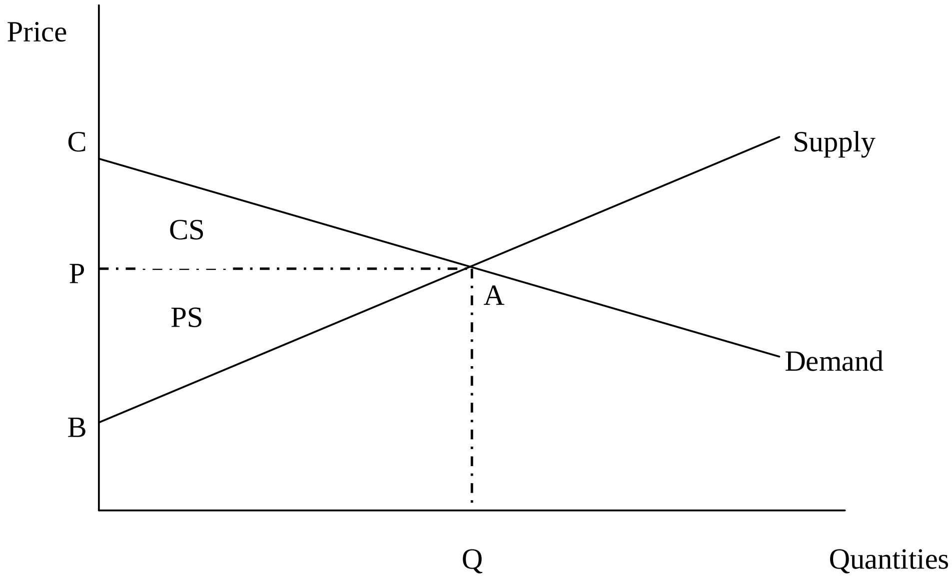

Figure 3.1: Partial equilibrium analysis: consumer and producer surplus
Source: Hareau (2002)

The impacts of technological change on PS and CS are presented in Figure 3.2. Technological change causes an outward shift in the supply curve from the original supply curve S to the new supply curve S_1. A new equilibrium is achieved at the new price P_1 and quantity Q_1. The total surplus change is reflected by the area BAA_1B_1 that is the sum of the change in PS and CS. The distribution of the change in total surplus between producers and consumers depends on the supply and demand elasticity (Hareau, 2002). For example, with a perfectly elastic demand curve the impact of a shift in the supply curve due to technological change affects PS (area BAA_1B_1), but has no impact on CS as the price will not change (Figure 3.3).

The shift of the supply curve also depends on the nature of the technological change that in turn affects the changes in total surplus. Figure 3.2 and 3.3 present a parallel shift of a linear supply curve for the case of small closed and open economies respectively. However, the shift can also be divergent pivotal, divergent proportional or convergent. The type of innovation causing the shift (biological, chemical, mechanical or organisational) affects the supply shift (Hareau, 2002).

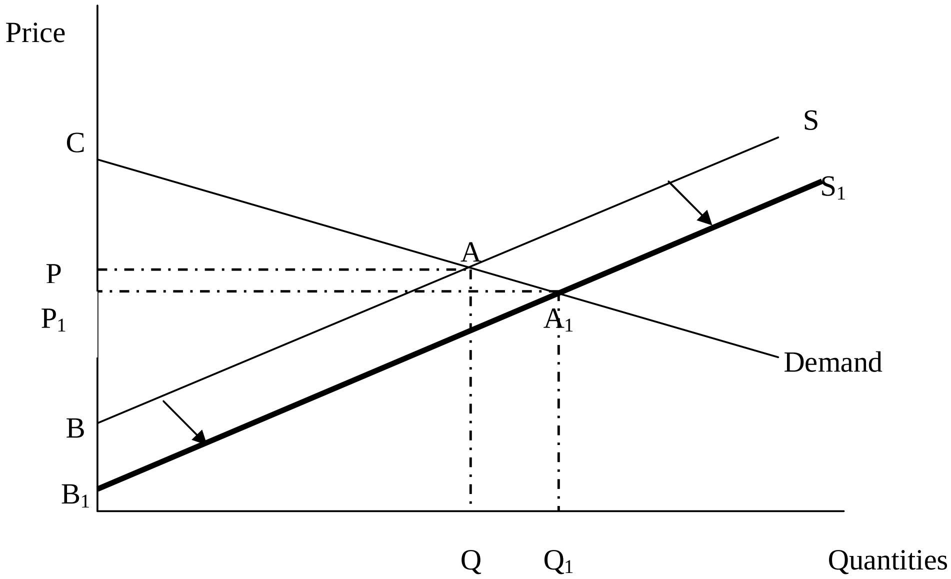

Figure 3.2: Change in total surplus with technological change
Source: Hareau (2002)

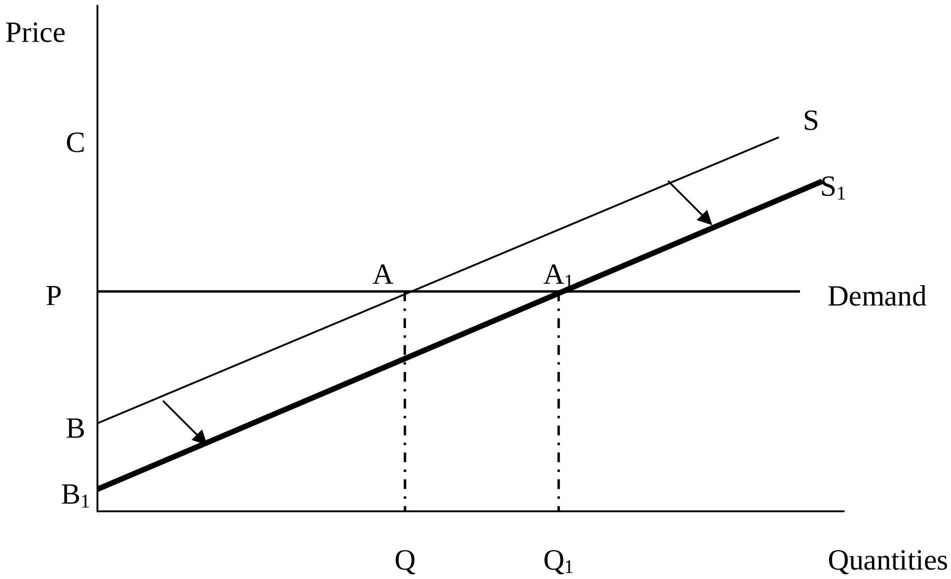

Figure 3.3: Change in total surplus with perfectly elastic demand curve
Source: Hareau (2002)

It should be noted that the price impact described above depends on the size of the country and the role it plays in the international market. Currently South Africa has a small market for cassava and is an importer, hence there is no effect; producing more cassava will not have an effect on the international prices nor, by extension, on local prices. Even if the current production increases in South Africa over the short term there will not be an impact on the price. However, if South Africa continues to produce more cassava with the introduction of GM cassava it is likely to have an impact on the price of cassava at a regional level. If production increases in a large exporter like Thailand, for example, the domestic and world prices are likely to decrease.

The advantages of the consumer and producer surplus approach are listed below:

- It provides a mechanism to analyse how the benefits of research are divided between producers and consumers. The distributive aspect is important if policy makers have a particular goal to improve the welfare of either producer or consumer.
- The approach may be applied to a closed or an open trade economy.
- It can factor in side effects of technology changes such as income distribution consequences and environmental consequences (Anandajaysekeram *et al.*, 2004).

However, the economic surplus model has some shortcomings as a measure of welfare changes. The economic surplus is based on normative economics that implies value judgements about the distribution of benefits between producers and consumers. When no explicit distributional assumptions are made, it implicitly means that equal weights are attached to producers and consumers. The economic surplus model is based on the compensation principle which makes value judgements relevant. The compensation principle states that if as a result of the new equilibrium winners and losers exist, the new equilibrium is still Pareto optimal if winners can compensate losers and still be better off than before (Hareau, 2002).

The other criticism against using PS and CS as welfare measures is that they are not exact money metric measures as they fail to consider the income effects of price changes. Alternative measures that are more precise and take into account the income effect in evaluating changes in utility are the Compensation Variation (CV) and Equivalent Variation (EV). The limitation of these approaches is that other sources of error from estimated demand functions associated with CV and EV reduce their precision and make the attempt irrelevant for the purpose of empirical analysis. Alternatively, changes in PS from the economic surplus model may be acceptable as a representation of changes in producer profits (Alston *et al.*, 1995; Hareau 2002).

Another cause of concern when using the economic surplus model are the errors associated with critical assumptions regarding the functional form of the supply and demand curves, the nature of supply shift and the supply and demand elasticity. However, these assumptions are often unavoidable in empirical analyses due to a lack of proper data or the cost of estimating their real form (Hareau, 2002).

The presence of externalities and transaction costs associated with the movement from the initial to the new equilibrium is another issue that needs to be addressed in the empirical analysis if the costs are significant enough to change the conclusions of the analysis. To account for this, externalities such as environmental impact can be valued and incorporated into the model as cost as well as transaction costs that become obsolete when change takes place (Alston *et al.*, 1995; Hareau, 2002).

The problems associated with understanding the economic surplus concept by economic agents and decision makers have been cited as reasons for making the approach irrelevant for policy analysis. However, this can be addressed by explicitly explaining the assumptions of the model (in other words, the distributional value judgements) and communicating the results in ways that addresses the needs of the target groups. Smale *et al.*, (2006) summarised the limitations of the economic surplus model:

- The approach ignores transaction costs and assumes that the market is clear and functions perfectly.
- The surplus calculated is Marshallian, accounting for price effects instead of changes in income.
- The approach fixes prices and quantises other commodities produced by farmers.
- The effect on the input market is not clear and the approach does not explicitly account for returns to land and labour which are important factors for measuring the impact of new technology.

- In this approach farmers are considered to be risk neutral price takers who either maximise profits or minimise costs.
- The approach requires reliable cross-sectional time series data which in most cases is not yet available for genetic modification technology in developing economies.

Despite these shortcomings the economic surplus model is argued to be the best available partial equilibrium surplus model to evaluate the returns to research (Alston *et al.*, 1995). The key advantage of the economic surplus model is that is parsimonious with respect to data and can be used to portray distributional effects (Scatasta, Wesseler and Demont, 2006).

3.3.5 Computable general equilibrium or simulation model

A CGE model considers the entire economic system when simultaneously determining prices and quantities in an economy while assuming perfect competition. In an ex ante study three conditions need to exist:

- a representative case study of production, export and preferences of agricultural commodity,
- commercialisation or near commercialisation of the commodity in another representative country, and
- a minimum acceptance of the new technology in the study area (Babu and Rhoe, 2003).

There is also a need for information regarding variables conditioned on the objectives of the study which are necessary to solve the following system of simultaneous equations: mark-up price, cost reduction, adoption rate, supply and demand elasticity, world price, per unit cost reduction in crop production, trade restrictions (tariffs and quotas) and production quantities of GM and non-GM goods (Babu and Rhoe, 2003). A CGE study may sometimes involve an analysis of scenarios regarding preferences for GM food. The analysis sheds light on four outcomes of adopting genetically modified crops: the GM product market, changes in the competition for primary production factors and inputs, changes in the cost-drive price of the modified crops, changes in the consumption pattern based on new relative prices and changes in import patterns due to the relative world price (Babu and Rhoe, 2003).

The major disadvantage of the CGE model is that it requires an extensive amount of data and the estimation of a number of mathematical relationships. The construction of a proper model requires much time and information. The other disadvantage of this type of model is that there is no scope for modelling market imperfections in the input sector (Smale *et al.*, 2006).

However, the major advantages of this approach are that the models are flexible and can be used to estimate optimal levels of new technologies at a national, commodity, or programme level as well as the effects of the new technology on prices, income and employment (Anandajaysekeram *et al.*, 2004).

3.4 Empirical studies measuring ex ante economic impacts of genetically modified crops

The following is a summary of ex ante studies from different literature sources arranged according to the assessment method or approach used. This section is included to illustrate how the abovementioned approaches were applied in different ex ante studies from literature and the results that were attained.

3.4.1 Empirical studies based on the partial budget approach

Alston *et al.*, (2002) estimated the likely economic impact of the commercial adoption of Monsanto's Yieldgard Rootworm in the United States. The study involved evaluating the farm level economic impacts into an estimated economy-wide impact. Data from 11 districts was used. The study assumed that all farmers in a particular agro-ecological region would adopt the technology in a year if it was expected to be more profitable than the next best alternative, subject to non-pecuniary risks. The results from the study varied according to the scenario and the region, but overall there were benefits. The total annual regional benefits, under the moderate scenario and based on the regional prices of corn in 2000 ($1.85/bushel) was $16.49 per acre treated.

Between the low and high scenarios, the estimated total benefits ranged from $8 to $29 per acre. The annual national benefit in 2000 using 2000 prices was estimated at $402 million.

The empirical simulation by Hareau (2002) used partial budget figures for potatoes and rice as a starting point to simulate the impact of transgenic varieties. They assumed that transgenic varieties have an impact on some variables of the partial budget, changing their value with respect to the benchmark figures representing the cost of producing under the actual or traditional technology. The key variables in the partial budget were the difference between the per hectare cost of inputs used in the traditional technology and the new per hectare cost of inputs under transgenic technologies, the expected increase in yield per hectare of the transgenic technology with respect to the traditional technology and the increase in price of transgenic seeds.

Hareau’s study (2002) accounts for the presence of imperfect competition in the Uruguay market for the transgenic seed due to the monopolistic nature of gene ownership. The is change in economic surplus generated after the adoption of the new technologies was found to be potentially positive, even though the seed mark-up charged by the monopolist reduces its magnitude compared to expected benefits in perfectly competitive markets. The domestic benefits in the economy decreased with the increase in the seed premium level, and many private profits were extracted out of the country. At the same time adoption was also lower, further reducing domestic benefits.

3.4.2 Empirical studies based on the cost benefit approach

Araji and Guenthner (2002) applied the cost benefit method to estimate the economic and environmental benefits of genetically modified potatoes. The data used in the study was total hectare of potatoes, the percentage of plants susceptible to late blight that required spraying, percentage of planting currently susceptible to late blight, and the percentage of toxic materials in each fungicide. Gross benefits included yield, storage loss reductions and a reduced fungicide cost. Adopting GM potatoes was estimated to increase yield by 5 percent, storage cost by 1.2 percent and to improve revenue by 3.2 percent. The study estimated the annual world gross benefit to exceed $4.3 billion. The value of GM potatoes over 25 years with a 6 percent discount rate would be $27 billion for producers. In addition to this an estimated 37 million kilograms of toxic ingredients would not enter the global environment (Babu and Rhoe, 2003).

Flannery *et al.*, (2004) measured the costs and benefits of GM crop cultivation in Ireland using the cropping regime of four crops (sugar beet, winter wheat, spring barley and potato) and comparing them with equivalent hypothetical GM scenarios. The figures used were based on crop production data for Ireland and included variable and fixed costs. The results of this study showed that cultivation of the listed GM crops in both 2002 and 2003 would have provided savings for the producer with a greater benefit recorded in 2002 for barley, wheat and sugar beet due to the higher chemical inputs. Based on the herbicide chemical cost and the cost of application it was demonstrated that under Irish climatic conditions, GM crops had the potential to economically outperform conventional varieties. In the analysis GM sugar beet cultivation could be economically beneficial to the Irish farmer in both the absence (9.69% savings) and presence (25.2% savings) of increased yields.

The findings of Flannery *et al.*, (2004) concurred with other similar studies (May, 2003) and underlines the potential economic benefit of commercial-scale GM sugar beet adoption to the industry. The potential economic benefit is the convenience factor associated with GM crop cultivation. It affords the producer the opportunity to reduce labour time and provides flexibility in their management practices since most Irish farmers work part-time. In addition, the adoption of GM crops at farm level is dependent on technology that is cost saving through a reduced need for pest and disease control. Overall, the analysis showed that the potential exists for GM crops to be more profitable for Irish farmers than conventional crops.

A study by Zimmermann and Qaim (2004) applied cost benefit analysis to measure the potential impacts of golden rice in the Philippines. Golden rice has been genetically modified to produce beta-carotene in the endosperm of grain for the improvement of the availability of vitamin A. A preliminary cost benefit analysis showed that research and development expenditures for golden rice were a highly profitable public investment. In the scenario the calculated internal rate of return ranged between 66 and 133 percent. These returns were higher than for many crop breeding projects focusing on the improvement of agronomic traits. The analysis demonstrated a high economic significance. The breeding programme was a promising and efficient way of reducing micronutrient deficiencies among the poor. The analysis was the first attempt to quantify the health impacts of micronutrient-enriched food crops within an economic framework.

3.4.3 Empirical studies based on the computable general equilibrium or simulation model

Nielsen, Thierfielder and Robinson (2001) adapted a CGE model to incorporate GMOs by segregating the markets into a GMO and non-GMO market. The study assumed that there is complete segregation of the markets: GM food processing industries would only use GM inputs and non-GM food processing industries would only use non-GM inputs. The study showed that in segmented markets traded patterns adjust according to consumer preferences. On the other hand, countries that prefer not to import GM goods will in fact export more non-GM goods which will have an impact on trade relations. The results suggested that there are large welfare gains for developing countries if productivity benefits outweigh GM seed costs.

Mills (1998) used a quadratic programming spatial equilibrium model to analyse the potential impact of maize research in six regions of Kenya. This ex ante model allows for reversible trade flows among multiple regions. Using the 1992 to 1994 retail maize data for over 30 markets across Kenya, the study estimated the transaction costs associated with inter-zonal trade. The study simulated the impact of research and other factors on Kenya’s maize market over a period of thirty years. Empirical results reflected high returns to continued maize research in Kenya.

In an effort to emphasise the anecdotal outcomes from CGE modelling, Boccanfuso, Decaluwe and Savard (2003) provided an overview of approaches used in modelling income distribution in a CGE framework. Six functional forms compared parametric and non-parametric estimations with the conclusion that no single form was found to be suitable in all household categories or groups. Their conclusion is supported by earlier work done by Metcalf (1972) suggesting that three to four parameter functions might be more appropriate to capture economic changes. Secondly, more flexible functional forms might have provided better insight when analysing the effects of CGE modelling on income variables.

Khan (2004) presented a CGE model to evaluate collective issues involving poverty, inequality and income distribution. The study simulated the impact of a fall in the export crop price and import tariff reform on poverty levels. The study intended to devise a methodology where a comparison could be made between the incidence of poverty in pre and post shock scenarios. The intra-group income distributions and the nominal poverty line were endogenised. This approach provided an assessment of the overall poverty in the country, but can also rendered insight into poverty levels relevant to specific groups or regions inside a country. The CGE approach has been recognised by many to be useful in analysing the income distribution and poverty as it recognises the coexistence of formal and informal types of activities in both rural and urban areas.

3.4.4 Empirical studies based on the consumer and producer surplus or economic surplus model

Soufi (2001) used an ex ante economic surplus framework to evaluate the economic impact of research into a drought tolerant groundnut (La Fleur 11) on the Senegal economy. The analysis was applied to an aggregated and a disaggregated market scenario. A closed economy model was used to conduct a farm level analysis, under the assumption that farmers sell unshelled groundnut output at the producer base price. In the disaggregated market scenario, the analysis was carried out separately for each La Fleur 11 market in the groundnut sector, using various modifications of the basic ex ante economic surplus model.

The modifications include a pivotal supply shift and a parallel demand shift due to population and income changes. In the aggregated scenario the findings in the groundnut sector were that consumers are the primary beneficiaries of research, with benefits averaging six times those of producers (farmers). However, for the disaggregated market, consumer benefits were three times higher than producer benefits at the farm level, while at export levels only the producers benefit from research. Soufi's findings encouraged support for the investment in the research of the La Fleur 11 groundnut variety in Senegal.

Pachico *et al.*, (2001) assessed the income and employment effects of herbicide resistant cassava in Columbia using the economic surplus approach and using dynamic research evaluation and management model software. Equilibrium outputs, prices and consumer and producer benefits were compared for three technologies: transgenic herbicide-resistance, conventional breeding mechanisation and current technology. The results showed that herbicide resistant cassava reduced the per hectare costs from $592 to $429. The adoption of this technology reduced manual weeding labour per hectare by 46 days. Furthermore, these reductions lowered the per tonne production cost by 34.1 percent. With a 5 percent discount rate, herbicide resistant cassava total benefits were estimated to be $508 million with consumers receiving approximately 40 percent of the benefit while non-adopting farmers become net losers.

Hareau (2002) analysed the economic impact of the introduction of GMOs in Uruguay's agriculture. The study used a partial equilibrium framework to simulate the impacts of transgenic varieties of rice and potatoes in small, open and closed economies respectively. The economic surplus model used in the study accounted for the presence of market imperfections created by the monopolistic behaviour of the gene's patent owner. The findings from the study showed that the adoption of new technologies had positive potential benefits to the economy, although monopolistic power reduced the surplus compared to a perfectly competitive market. The results of the study suggested an active role for national policies and for agricultural research and development would be beneficial.

Hareau *et al.*, (2004) used an economic surplus model to analyse the economic impacts of the Uruguay rice project. Stochastic simulations and an endogenous adoption of the economic surplus framework showed the Uruguay rice project had minor potential benefits because of the small production base, especially considering the fact that multinational companies are likely to develop locally adapted transgenic rice varieties without strategic partnerships with local institutions. The study concluded that the genetically engineered trait would pay off with high yields.

Qaim (1999) analysed the effects of biotechnology on semi subsistence agriculture. The study focused on the ex ante economic implications of transgenic virus and weevil resistant sweet potatoes in Kenya. The model calculations showed that both innovations were likely to bring about substantial growth in economic surplus. This study was carried out prior to field tests of

GM sweet potato. However, after these trials it was found that the first generation of GM sweet potato did not have higher yields as was expected.

De Groote *et al.*, (2003) and Mugo *et al.*, (2005) evaluated the impact of insect resistant maize in Kenya by applying the economic surplus approach. The study used detailed farm level production practices data on and on-farm trial data measuring crop losses. The results of the study showed a policy dilemma for the Kenyan government to consider. About 80 percent of the estimated value of crop losses to stem borers in Kenya accrues in the moist transitional and highlands zones where the adoption rates for maize hybrids were greatest and where the nation's surpluses were produced. Only 12.5 percent of the national value of crop losses to stem borers occurred in the lower potential, dry and lowland tropics zones. Although maize yields were much higher in the high potential zone, losses to *Chilo partellus* against Cry proteins in Bt maize were found to be very low. The equity impact of developing materials for low potential zones could be substantial since farmers had fewer alternative sources of income and were generally unable to meet their maize subsistence requirements from their own production.

Falck-Zapeda, Traxeler and Nelson (2000) used the consumer and producer surplus approach to analyse the distribution of transgenic cotton benefits in the United States (US) among the different populations under the monopolistic regime caused by intellectual property rights regulations. The study estimated the technology-induced supply shift for each selected region. The analysis also calculated world and regional prices resulting from the shift and estimated the consumer and producer surplus distribution in domestic and international markets as well as monopoly profits. The data used in the study were yields, input prices, adoption rates and world price. The results showed that US farmers received $140.8 million, Monsanto (a biotech innovator) received $49.8 million and Delta and Pine Land (a seed company) received $13.2 million in surplus. The consumer surplus for the US was $21.6 million. The consumer surplus for the rest of the world was $36.5 million, while the rest of the world producer loss was $21.6 million.

Qaim (1999) analysed the impact of transgenic virus resistant potatoes in Mexico on social welfare using the consumer and producer surplus approach. Demand and supply functions were modelled as linear curves and the technology was assumed to cause a parallel downward shift in the supply function. The model was run from 1999 to 2015 after the 2004 demand became perfectly elastic in price due to openness to trade and the North American Free Trade Agreement. Producers were divided into three different groups according to size (small, medium and large). The authors determined values for the supply elasticity of the three different groups of producers and farm level benefits were assumed to be positive based on expert opinions. The authors found large benefits for consumers and producers of all sizes. A sensitivity analysis was carried out regarding the per unit cost reduction and supply elasticity which was allowed to vary between 0 and 2. Changing these parameters resulted in a change in size, but not direction. The authors showed that as the supply elasticity increases, the benefits to small producers become smaller.

3.5 Selected approach of the study

For the purpose of this study and due to available data, a simple gross margin analysis to analyse the economic profitability of genetically modified cassava in South Africa was applied in comparison with maize and potato. Due to severe data limitations, this study had to rely on the synthesis of secondary information from various studies in other African countries as well as on expert interviews. The information collected was used to assess the potential benefits of genetically modified cassava in South Africa. As cassava is not a popular crop in South Africa, data on cassava root production and cassava starch production is severely limited. The fact that limited to no data on cassava production is available is partly caused by a single market player, arguably rationally, defending his monopolistic position in the market and private and public institutions' general less investment in research and interest in this crop. Secondary sources and expert interviews were used to provide more insights and information relating to possible market opportunities, constraints, performance of the genetic events and production practices for cassava and other competing crops like maize and potato in the country.

Experts in the cassava sub sector in the country were strategically selected. The interviewed experts include: the Managing Director of CSM and senior researchers at the South African Agriculture Research Council (ARC) Institute for Industrial Crops in Rustenburg who are innovators in GM technology. CSM is the biggest producer of the cassava crop and cassava starch and is an importer of cassava (starch, chips or wheat), mainly from Thailand. The company is the sole domestic supplier of cassava starch to the South African food and manufacturing industry. Information on the GM constructs and expected performance was requested from foreign study leaders.

Senior researchers at the Institute for Industrial Crops provided useful information on genetic trends in cassava in the country as well as information relating to constraints and perceptions on the crop. The researchers are responsible for breeding. They have been working with cassava cultivars in South Africa and researching how they can best keep their cultivars clean from the mosaic virus. They are also in the process of compiling data for cassava subsistence farmers in rural South Africa where production is taking place and little has been done to gather information. They are also examining the prevalence of the mosaic virus in the rural areas.

3.6 Summary

The various approaches and methods that have been used to measure the ex ante economic impacts of genetically modified crops have been discussed. In addition, the chapter reviewed empirical studies of these methods in ex ante analyses of biotechnology crops. Ex ante economic impacts of genetically modified crops have been estimated using a number of approaches: cost benefit analysis, partial budget approach, the consumer and producer surplus approach, the computable general equilibrium or simulation model, and the economic surplus model.

For the purpose of this study and due to available data, a simple gross margin analysis to analyse the economic profitability of genetically modified cassava in South Africa was applied in comparison with maize and potato. Due to severe data limitations, this study had to rely on the synthesis of secondary information from various studies in other African countries as well as on expert interviews. The information collected was used to assess the potential benefits of genetically modified cassava in South Africa. As cassava is not a popular crop in South Africa, data on cassava root production and cassava starch production is severely limited. The fact that limited to no data on cassava production is available is partly caused by a single market player, arguably rationally, defending his monopolistic position in the market and private and public institutions' general disinvestment in research and interest in this crop. Secondary sources and expert interviews were used to provide more insights and information relating to possible market opportunities, constraints, performance of the genetic events and production practices for cassava and other competing crops like maize and potato in the country.

No ex ante assessment of the potential impacts of introducing GM cassava has been done in South Africa to answer the above question. This study fills this empirical gap by evaluating the potential economic impacts of introducing genetically modified cassava in South Africa. The ex ante evaluation of the potential impacts of introducing genetically modified cassava is of importance in informing policy discussion on the promotion and adoption of GM cassava for commercial, industrial and food uses.

CHAPTER 4

Cassava utilisation and market opportunities for commercial cassava starch applications in South Africa

4.1 Introduction

This chapter discusses cassava utilisation and opportunities for commercial cassava starch applications in South Africa. The chapter starts by presenting all potential utilisations and applications for cassava. This is followed by a detailed discussion of the industrial applications of cassava starch and opportunities for commercial cassava starch utilisation in South Africa.

4.2 Cassava utilisation and applications

The cassava shrub contains roots and leaves which can both be processed to make various products. Even though cassava leaves' uses are by no means limited, the roots are the main reason for cassava production. Figure 4.1 presents the various products that can be derived from cassava's roots. Cassava products fall into three broad categories: products for human consumption, animal consumption and industrial applications. These categories are discussed in detail below.

4.2.1 Human consumption

Both cassava roots and leaves are suitable for human consumption. The roots are an important source of carbohydrates and the leaves of proteins and minerals (Kilimo Trust, 2007). Various traditional methods have been developed in different countries to prepare cassava that include peeling, boiling, baking, frying and grating to extract starch (Goldstuck, 2006; Ceballos *et al.*, 2004). The refined product is then dried over a fire or left in the sun to dry for 2 to 3 days after which it is added to soups and stews as a thickener or fermented and cooked. The starch extracted from the processing can be used to make bread, sago, crackers or pasta. The leaves of the cassava plant are edible and provide a rich source of protein and are eaten as a green vegetable (Ceballos *et al.*, 2004).

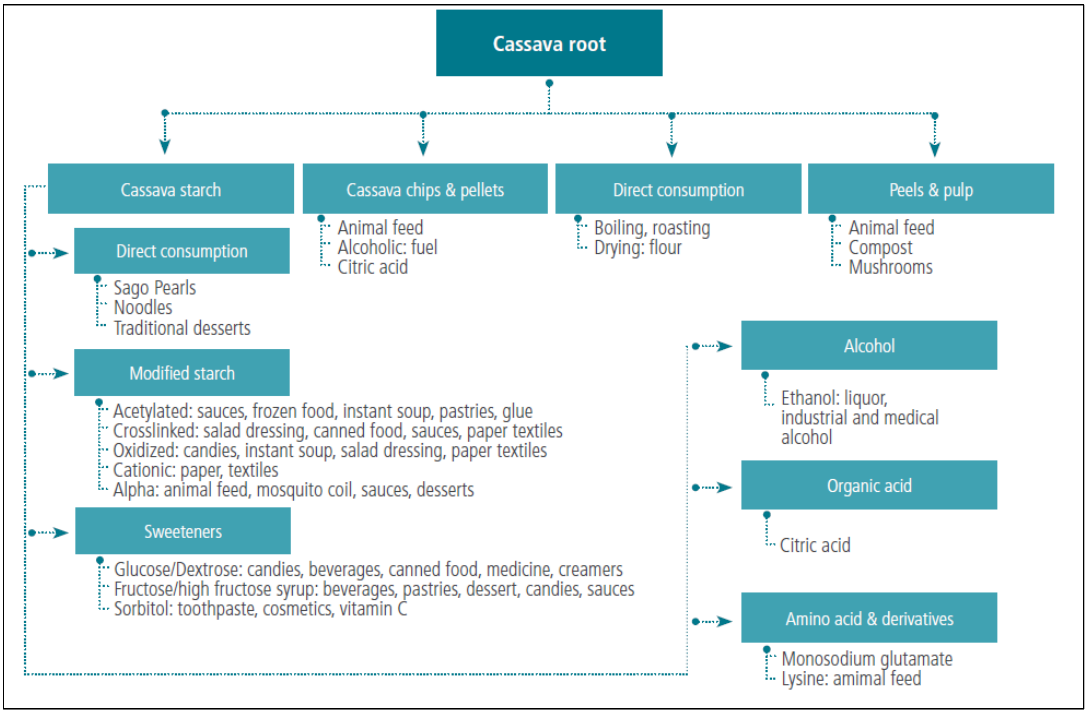

Figure 4.1: Products derived from cassava's root
Source: Goldstuck (2006)

The need for cassava as a raw material in developing countries has been increasing each year by 2 percent for food and 1.6 percent for feed. Based on the 2006 cassava production levels, cassava production levels were projected to reach 168 million tonnes in 2020 (Sudarmonowati *et al.*, 2006). Another potential growing market lies in the growing demand for the processing and marketing of cassava products for human consumption to developed countries' specialised markets. For example, an increased awareness of healthy eating among consumers can lead to the use of cassava's dried roots since they provide an alternative source of carbohydrates for people with wheat, corn or rice allergies. Furthermore, cassava products can be marketed to consumers who have a taste for exotic and healthy foods that have a low fat and sugar content. Cassava absorbs less fat when it is fried than other starches making it a healthier alternative to produce snack and convenience foods (Goldstuck, 2006).

The marketing of cassava based products, especially for human consumption, is affected by negative consumer perceptions. For example, cassava is considered to be a famine food with low nutritional value and cassava flour is generally not sought after (Kilimo Trust, 2007). In addition, there is likely to be stiff resistance to the spread of cassava products from the market's incumbents as they have already invested substantially in technology that favours potato and other starch based products (Goldstuck, 2006). It is imperative that a cassava marketing strategy include campaigns to change consumer perception, for example, through road shows, advertisement and programmes on radio and television.

4.2.2 Animal feed

Cassava is also processed into animal feed. The roots can be processed into either pellets or chips that are used as animal feed for cattle, sheep and poultry. Bitter cassava varieties are the preferred kind for this scope because of their high starch content, although they are not popular for human consumption because they require careful processing before being eaten because of the presence of cyanide (Kilimo Trust, 2007). While the roots contain a very high carbohydrate level, the protein and vitamin content are poor and animal feed from cassava must be supplemented with soy meal or leaves from the cassava plant (ITC, 2003). The processing of cassava roots into chips involves slicing them into pieces not longer than 5cm for storage in silos and drying them in the sun for 2 to 3 days or until the moisture content is between 13 and 15 percent (ITC, 2003).

The cassava roots can be trimmed, peeled and washed before processing to create a superior quality product. Generally, 2-2.5kg of fresh cassava roots is required to produce 1kg of chips (ITC, 2003) translating into a recovery rate of roughly 20 to 40 percent (International Starch Institute, 2007). This process produces a by-product which could be used to make cassava meal. However, cassava meal is categorised as an inferior product compared to cassava chips, pellets and broken roots because of its lower starch content, higher impurity content and since it is more difficult to transport (Goldstuck, 2006).

There are simple potentially profitable processing techniques for small scale farmers to produce acceptable cassava products for the livestock feed industry. This presents an opportunity for farmers and small scale businesses to invest in a chipping factory to acquire a share in the value-added product market. As a result of the perishable and bulky nature of cassava, processing must be done in close proximity to the growing areas. This implies that the benefits arising from value-added activities are trapped in communities where cassava is grown (Goldstuck, 2006; Bokanga, 1995).

Cassava pellets are processed from chips. The process involves mixing chips with palm oil, grinding, steaming, dyeing and cooling the product into a cylindrical shape roughly 2-3cm long and about 0.4-0.8cm in diameter (ITC, 2003). Cassava pellets are regarded as a superior value-added product compared to chips for a number of reasons: the pellets' product quality is more uniform than chips; pellets are more compact and occupy 25 to 30 percent less space than chips helping reduce transportation through lower handling charges for offloading products and storage costs; and pellets are a more stable, sturdy product and reach their destination with considerable less damage than chips (Goldstuck, 2006).

The ever increasing demand for cereals by humans and livestock in most countries in Africa presents an opportunity for cassava starch utilisation as a substitute for maize and wheat processed feeds. According to the Bureau for Food and Agricultural Policy's (BFAP) baseline report of 2009 there have been changes in consumer preferences – there is a higher demand for meat than grain. This means the animal feed industry has to expand and produce more feeds. The cassava based animal feed market in South Africa has high potential, but currently does not "exist" due to institutional and supply side factors. There is a need to explore creating local and regional markets for cassava based animal feeds in the country.

4.2.3 Cassava starch industrial uses and applications

The production and use of cassava starch presents an important alternative to maize, wheat, rice and potato. Cassava starch has a wide range of applications in both food-related and non-food-related industries such as the adhesives, explosive, paper, construction, metal, textile, cosmetic, pharmaceutical, mining and food industries, and can be used for a host of applications within markets (Sudarmonowati *et al.*, 2006; Goldstuck, 2006; Ceballos *et al.*, 2004; Bokanga, 1995). The following sections briefly discuss the widespread use and applications of cassava starches.

There are many opportunities for chemically modified cassava starch in a market that is currently dominated by modified cereal starches. For instance, drying cassava starch at 70˚C produces short-textured pastes with lowered viscosities which are preferred for pie fillings, cream puddings and the production of baby foods. Dextrins produced from cassava starch can be formulated into better adhesives ideal for gums for envelopes, postage stamps, bottle labelling adhesives, lined cardboard boxes and in binding pigments for the glass fibre industry (Bokanga, 1995).

Cassava roots can be used to produce native or modified starch (Ceballos *et al.*, 2004). Starches that are subject to value-additions are called "modified starches" as opposed to unmodified "native starches" (Kilimo Trust, 2007). These starches can be used either as a finished product or as a raw material to create a substance that is used in the manufacturing process. Modified starches are produced by manipulating a native starch's intrinsic physical, chemical or micro-biological processes to meet specific user application requirements. For example, cassava starch would need to be modified to produce biodegradable plastics or any application that requires properties associated with a low amylose content (Goldstuck, 2006).

Native and modified starches are used to produce sweeteners (maltose, glucose syrup, glucose and fructose), hydrogenated sweeteners (sorbitol, mannitol and maltol) and Monosodium Glutamate used in food processing. However, these starches are not perfect substitute products, even though they are used in cross-over markets. For example, a native starch would be preferred in certain markets where consumers are against modified products such as the baby food market (Howeler, 2003). Generally, modified starch is used in "heavy" manufacturing applications such as the paper industry, textile industry (warp sizing, cloth finishing and printing), construction materials, and pharmaceuticals.

Globally, the demand for processed foods, paper products, biodegradable plastics and cosmetics continue to rise and these products are produced using starches. The market for starch is growing as economies continue to industrialise and consumerism spreads into peri-urban and rural areas, changing people's cultural preferences and values, altering their lifestyles and what they consume (Goldstuck, 2006).

Although the market for starches is growing, the pertinent question is whether the market for cassava starch is growing. This requires exploring what type of products are demanded, whether cassava starch has the properties to cater to this market, and whether cassava starch can face competition from substitute products. For example, native cassava starch has ideal properties to be used by the food industry to produce processed foods and sweeteners. On the other hand, cassava starch would need to be modified to produce plastics or any product that requires a "waxy" compared to a "gel-like" substance (Sudarmonowati *et al.*, 2006; Goldstuck, 2006).

Substitutes for cassava starch are maize, potato and wheat. The dominant market position of these starches is due to historical usage patterns, the continued development of products that require these starches' properties and the fact that the producers of these starches reside in developed countries and thus have the resources to conduct scientific research to create new applications for these starches. For cassava starch to gain a sizable market position, research is required into its properties and the development of modified starches "with specific properties that make them preferable for certain industries" (ITC, 2003).

The increasing demand for starch based applications in the food industry and industrial sector and the fact that the industry is searching for a cheaper substitute to cereals, presents an impressive market growth potential for cassava starch. For example, an emerging market for cassava starch is to produce biodegradable products, such as packaging material and kitchenware. Discarded plastic products have the potential to cause pollution, and as a result discarding these products places a burden on municipalities' waste management systems (ITC, 2003).

The great economic importance of starches has stimulated much interest in the potential to modify their properties through genetic engineering. Starch is an important raw material for industrial applications, such as in the paper, textile, plastics, food and pharmaceutical industry. It is currently being used in the production of biodegradable packing materials and in the development of biodegradable plastics, which is becoming an increasingly attractive alternative to petroleum-based products (Sudarmonowati *et al.*, 2006).

4.3 Important cassava starch characteristics

The suitability of the various types of starches to particular applications depends on the physico-chemical properties of the starch granules, including their size, shape and surface as well as their amylose and amylopectin content. The amylose to amylopectin ratio determines factors such as the viscosity, gelatinisation, texture, solubility of the starch. The starch characteristics can be enhanced through value adding techniques ranging from simple sterilisation, centrifugation and pre-gelatinisation to highly complex chemical transformations (Kilimo Trust, 2007). Table 4.1 summarises the products derived from different forms of cassava starch.

Table 4.1: Products derived from different forms of cassava starch

Produced from starch-normally modified	**Produced from roots or dried roots**	**Produced from starch-normally native**
Biodegradable products (plastic bags, soup bowls, lunch boxes and cups)	Food (gari, fufu flour commonly consumed in Nigeria, tapioca meal and lafun)	Alcohol
Pharmaceuticals (used in pills and tablets, syrups and face creams)	Flour (used for baking and is popular for being gluten free)	Glue
Prepared food (used in sausages and prepared meats)	Animal feed (processed into chips and pellets)	Plywood
Sweeteners (glucose syrup)		Paper (because of its whiteness it is a favourable characteristic in producing paper)
Monosodium Glutamate (used in soups, sauces and gravies)		Textiles (used at the sizing, finishing and printing stage)

Adapted from World Cassava Economy (FAO, 2000)

The production and use of cassava starch presents an important alternative to maize, wheat, rice and potato. Cassava flour and starch have unique properties which make them ideal for many applications in the food, textile and paper industries where flour and starch from the other crops have a quasi monopoly (Bokanga, 1995). Among starch producing plants, cassava has been considered as the highest producer (25 to 40 percent higher than rice and maize) and as the most efficient (the highest) converter from solar energy to carbohydrates per unit area (Sudarmonowati *et al.*, 2006). Four to five tonnes of roots are normally required to produce one tonne of cassava starch, but the ratio may be as high as ten to one, depending on the quality of the root (Kilimo Trust, 2007).

Cassava starch, because of its high amylopectin content, forms clear, fluid, non-gelling pastes with little tendency to shear. In addition, it has the lowest gelatinisation temperature compared to maize, wheat and potato starch implying that it consumes less energy during cooking (Bokanga, 1995). There are many opportunities for chemically modified cassava starch in a market that is currently dominated by modified cereal starches.

Cassava starch has a wide range of applications in both food-related and non-food-related industries. For example, cassava starch could be converted to maltotriose, maltose, and glucose and other modified sugar and organic acids. Starch hydrolysate has been widely used as additive compound in food industries (candies, bread, canned food and frozen food). Certain industries require very low amylose levels because it is not easily digestible for paper filling while other industries require very low amylopectin levels (Sudarmonowati *et al.*, 2006).

4.4 Opportunities for commercial cassava starch utilisation in South Africa

The international starch market is highly competitive and is dominated by corn, maize and potato starch products. These crops are argued to have benefited from substantial scientific research and this presents a technological advantage compared to cassava (Sudarmonowati *et al.*, 2006; Goldstuck, 2006; Bokanga, 1995). The potential for cassava in the South African market is rooted in improving its supply aspects by increasing production through increased acreage under cassava production. Another key area for cassava's future prospects in South Africa is improving processing technologies, specifically implementing intensive production and processing methods for small scale farmers. To enhance the potential of cassava utilisation for commercial uses it is crucial to ensure that farmers have access to biotechnology and extension services (Goldstuck, 2006). Table 4.2 shows the current raw materials used in different industries in South Africa and the potential alternative, cassava.

Table 4.2: Potential industrial use of cassava in South Africa

Industry	Current raw material	Potential alternative
Bread making factories	Wheat flour and rye	Cassava flour
Bakeries	Wheat flour and corn flour	Cassava flour
Processed food (sauces)	Maize starch	Cassava starch and cassava flour in sausages
Industrial alcohol	Sugarcane molasses and maize starch	Cassava derived sugar syrup
Animal feed	Maize and wheat	Cassava chips and pellets
Textiles	Modified maize starch	Cassava starch
Plywood	Modified maize starch	Cassava starch
Paperboard	Imported maize starch adhesive and cassava starch (Mondi and Sappi)	High quality cassava starch
Pharmaceutical	Modified maize and unmodified maize starch	Cassava starch
Laundry (dry cleaner)	Modified maize starch	Cassava starch

Source: Tongaat Hullet (2008) and Casey (2008)

The cassava starch industry in South Africa produces about 20 000 tonnes of cassava starch while about 25 000 tonnes are imported from Thailand (Casey, 2008). The market for cassava starch is mainly in the paper and food industry; however, new industries are being targeted for future expansion. In the paper industry Sappi and Mondi are the main industrial starch buyers while in the food industry companies like Enterprise Foods use cassava starch in sausage and polony binding. Table 4.2 below shows the estimated percentages of starch that is used by different industries.

Table 4.3: Current utilisation of cassava starch in South Africa

Industry	Percentage
Paper (Mondi and Sappi)	40
Food (e.g. Enterprise Foods meats and Lucky Star fish)	30
Miscellaneous	30

Source: Personal interview with Casey (2008)

4.5 Summary

This chapter discussed cassava utilisation and opportunities for commercial cassava starch applications in South Africa. Cassava products fall into three broad categories: products for human consumption, animal consumption and industrial applications. Cassava starch has a wide range of applications in both the food-related and non-food-related industries. The special characteristics of cassava starch present an important alternative to maize, wheat, rice and potato. Cassava flour and starch have unique properties which make them ideal for many applications in the food, textile and paper industries where flour and starch from the other crops currently dominate the market.

The increasing demand for starch based applications in the food industry and industrial sector and the fact that the industry is searching for a less expensive substitute presents an impressive market growth potential for cassava starch. In South Africa, industries such as the paper industry, food industry and textile industry are the main buyers of cassava starch. Increasing cassava utilisation by the food and feed industries provides a stimulus for increased cassava production in South Africa.

CHAPTER 5

Opportunities for genetically modified cassava in South Africa

5.1 Introduction

As outlined in Chapter 1, the main objective of the study is to evaluate the economic potential and opportunities for introducing GM cassava that is CMV resistant and is amylose free with improved starch properties in South Africa. The expected benefits from the production of GM cassava are twofold: (a) reduced crop yield losses as a result of the control of CMV with a virus resistant cultivar and (b) an amylose free and better quality starch cultivar.

African cassava mosaic disease is one of the most economically important virus diseases of cassava (*Manihot esculenta* Crantz). The disease is widespread in Africa reducing the overall yield of cassava by about a third (Thresh and Otim-Nape, 1994). On the other hand, GM cassava that is amylose free and has better starch properties, provides starch with important characteristics in the starch industry. The amylose free starch has an improved paste stability (freeze/thaw stability) which is the ability of a product to maintain its composition and integrity after repeated cycles of freezing and ambient temperature levels. This is expected to be an important characteristic for application in both the food and paper manufacturing industries..

Amylose free starch reduces the cost of starch production for industrial uses and avoids the use of chemicals which might be environmentally unfriendly such as expoxides (propyleneoxide, ethlyne oxide) and acetic acid (Reamakers *et al.*, 2005). Expoxides are explosive and cause skin diseases like industrial eczema to people who work with these chemicals. From a consumer perspective, with consumers increasingly more concerned about the use of chemicals in what they eat, and from an environmental view it would be advantageous if freeze–thaw stability could be engineered without the use of chemical treatments which are expensive and also environmentally unfriendly (Joblings, 2003).

The presence of amylose reduces the shelf-life of cassava tubers and the starch quality (Reamakers *et al.,* 2005). Genetically modified cassava that is amylose free offers great potential for improving the competitiveness of cassava utilisation for food and starch production for industrial uses from waxy or amylose free starches compared to other starch sources like maize and potato. Since cassava produces more starch per hectare and the starch properties are of a better quality compared to maize and potato, GM cassava will stand as a more competitive crop in the starch markets since it provides the desired properties for starch production.

This chapter discusses the impacts of cassava mosaic disease and opportunities for genetically modified cassava that is resistant to cassava mosaic virus and disease in South Africa. The chapter starts by presenting the historical background of the cassava mosaic virus, its causes and distribution and prevalence in Africa. This is followed by a discussion of the economic impacts of cassava mosaic disease as well as a discussion of cassava mosaic disease in South Africa and opportunities for genetically modified cassava that is resistant to cassava mosaic virus and disease. The chapter also presents a comparison between the gross margins of cassava, maize and potato, showing how cassava is an important crop in starch production. There is also a discussion of scenarios in which the effects of the mosaic virus on cassava yields and starch yields will be discussed in order to show how amylose free cassava will fetch different prices at different percentage levels. The chapter ends with a discussion of interviews with experts in South Africa regarding their views on genetically modified cassava.

5.2 Historical background of cassava mosaic disease

Cassava mosaic disease was first recorded in what is now Tanzania towards the end of the nineteenth century (Warburg 1894 in Legg and Thresh 2003) although its history remained unclear for many years (Legg and Thresh, 2003). The disease was later reported in many other countries in eastern, western and central Africa and is now known to occur in all cassava-growing countries in Africa and the adjacent islands as well in South Asian countries like India and Sri Lanka (Mabasa, 2007). In West Africa, CMD was first reported in the coastal areas of Nigeria, Sierra Leone and Ghana in 1929 while in East Africa, it was reported to cause serious damage in the 1920s and by 1945 it was reported to have spread northwards (Fauquet and Fargette, 1990).

Six distinct cassava mosaic geminiviruses (CMG) species have been identified and associated with cassava in Africa (Fauquet and Stanley, 2003):

- *African cassava mosaic virus* (ACMV)
- *East African cassava mosaic virus* (EACMV)
- *East African cassava mosaic Cameroon virus*-Cameroon (EACMCV-CM [CM:98])
- *East African cassava mosaic Malawi virus*-Malawi (EACMMV-[MW/MH:96])
- *East African cassava mosaic Zanzibar virus*-[Tanzania: Uguja: 1998] (EACMZV-[TZ: Ugu:98])
- *South African cassava mosaic virus* (SACMV-[ZA])

Prior to 1994 only ACMV and EACMV were known to infect cassava in Africa and were thought to be limited to specific geographical areas. ACMV was believed to occur only in West Africa and EACMV in East Africa (Swanson and Harrison, 1994). Improved diagnostic techniques and the advent of the polymerase chain reaction have resulted in a better understanding and appreciation of the complexity of the viruses' distribution (Mabasa, 2007). Several strains and/or species have been identified in the past thirteen years in different regions of the African continent. For example, several studies have shown the presence of ACMV in all parts of the continent where cassava is grown and EACMV is now found in West Africa as well (Mabasa, 2007). Berrie *et al.*, (1997) isolated SACMV in South Africa which shares a high nucleotide sequence similarity with EACMV. SACMV has also been found in Madagascar and Zimbabwe (Briddon *et al.*, 2003).

Until recently, the two viruses were considered to have distinct, largely non-overlapping distributions: ACMV was thought to occur in West, Central and central-southern Africa and EACMV was thought to be largely restricted to the East African coast, Madagascar, Malawi and Zimbabwe (Swanson and Harrison, 1994). However, more comprehensive recent surveys have shown that EACMV occurs over a much wider area, including western Kenya, western Tanzania, north-eastern Zambia, Nigeria and Togo and have identified areas where the two viruses occur together (Legg and Okao-Okuja, 1999; Ogbe *et al.*, 1997). Improved diagnostic techniques have also resulted in the identification of other viruses. For example, in Uganda, a virus variant which appears to be a recombinant hybrid of EACMV and ACMV has been detected which has been referred to either as the Uganda variant (Zhou *et al.*, 1997) or as a distinctive strain of EACMV (EACMV-Ug) (Deng *et al.*, 1997) and in South Africa, SACMV (Rey and Thompson, 1998). Cassava mosaic disease, caused by a group of begomoviruses, which belong to the family *Geminiviridae,* is the most important disease affecting cassava production in Africa (Harrison, 1985).

Figure 5.1 presents the first cassava mosaic geminivirus distribution map for Africa (Swanson and Harrison 1994). Legg and Thresh (2003) provided an updated known distribution of cassava mosaic geminiviruses in Africa based on 2002 information (Figure 5.2).

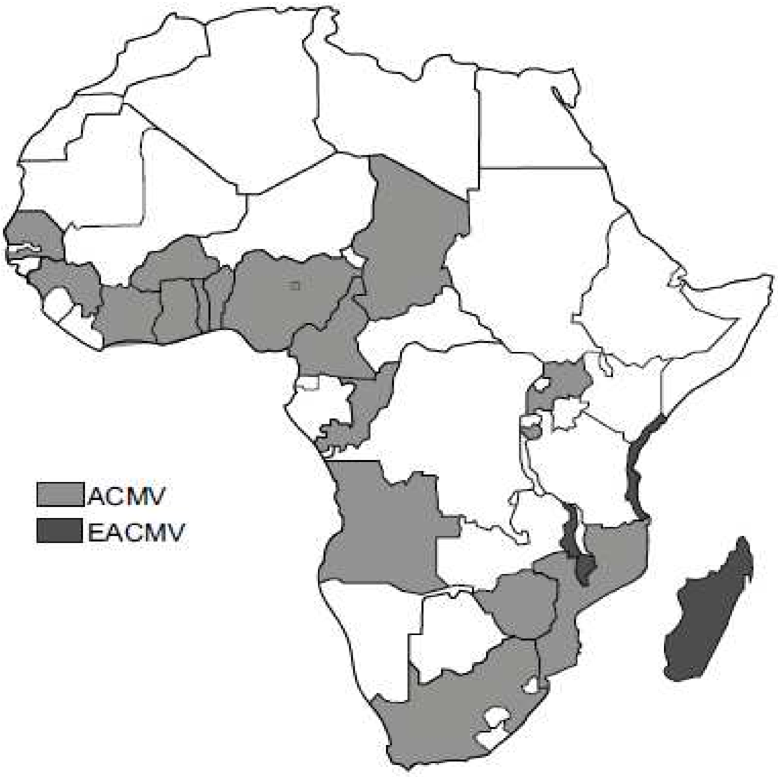

Figure 5.1: Known distribution of cassava mosaic geminiviruses in Africa: 1994
Source: Legg and Thresh (2003)

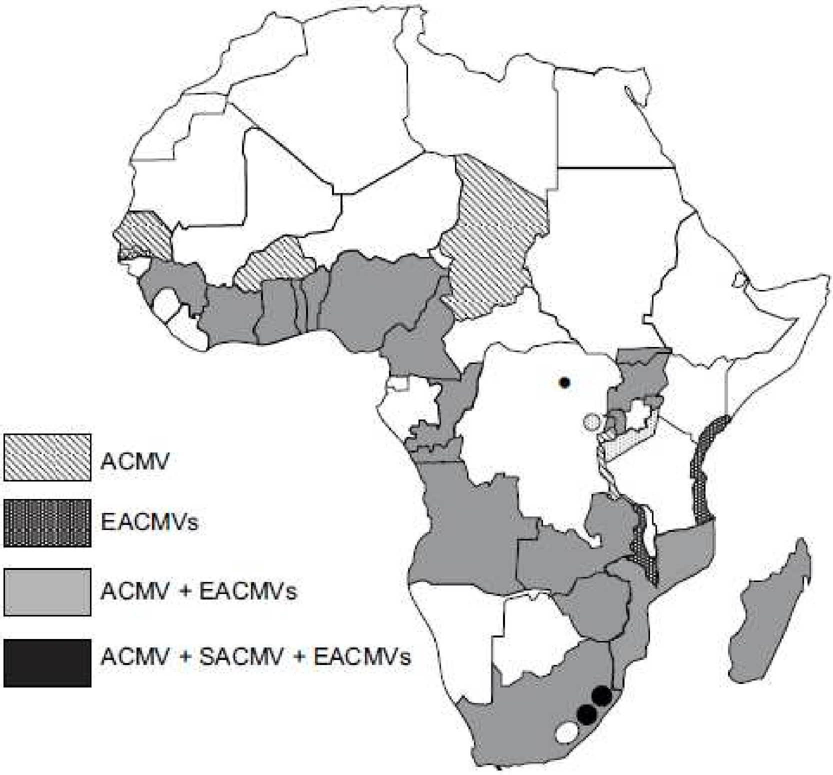

Figure 5.2: Known distribution of cassava mosaic geminiviruses in Africa: 2002
Source: Legg and Thresh (2003)

Information on the properties, distribution, effects and economic importance of most of these viruses are limited. *Begomovirus*: cassava mosaic geminiviruses of the family *Geminiviridae* are the most economically significant viruses of cassava in Africa as a whole while *Ipomovirus*: *cassava brown streak virus* (CBSV) is important in some parts of Africa such as Mozambique (Mabasa, 2007). Cassava mosaic viruses are transmitted by the whitefly *Bemisia tabaci* (Gennadius) to dicotyledonous plants (Legg and Thresh, 2003).

5.3 The causal agent of cassava mosaic disease

Cassava is a vegetatively propagated crop and virus diseases are carried from one crop cycle to the next through stem cuttings that are used as planting material (Mabasa, 2007). The viruses causing CMD are disseminated either through planting infected stem cuttings, or transmitted by a whitefly vector (Bock and Woods, 1983). No transmission through true seed or by naturally occurring mechanical processes have been reported (Legg, 1999). CMD symptoms are easily recognised by the appearance of the characteristic leaf mosaic (see Figure 5.3). The most severe symptoms result in the stunting of the plant and extreme reduction of the leaf surface area with consequent reduction in root yield (Mabasa, 2007).

Figure 5.3: Cassava plant with CMD
Source: Sparks et al. (2008)

The importance of various factors that influence the pattern of the spread of virus disease within and between fields and the factors that inhibit or favour such spread have been discussed in a number of studies. For example, Fauquet and Fargette (1990) reported that the incidence of CMD largely reflects fluctuations in whitefly populations which partly depend on climatic factors including temperature, rainfall and wind. High temperature has been argued to be the primary factor driving the increase in whitefly populations (Fauquet *et al.*, 1985, Fargette *et al.*, 1993). However, in some circumstances this may not be the case, for example, in situations where drought limits plant growth (Mabasa, 2007) or in the event of an epidemic such as the one that occurred in Uganda in the early 1990s where the epidemic was observed to be spreading rapidly into somewhat cooler areas (Legg and Ogwal, 1998).

Higher rainfall and humidity have also been positively correlated with a higher CMD incidence that results from higher whitefly populations that are supported by vigorous plant growth (Robertson, 1985). For example, in Tanzania the regions with the highest incidence were shown to be hot, wet coastal areas as well as drier inland areas moderated by neighbouring lakes (Legg and Raya, 1998). In addition, wind speed and direction is argued to influence the distribution of the whitefly population in a field and it has been shown that the incidence of CMD was higher on the upwind edges than on the downwind edges of the field (Fauquet and Fargette, 1990).

A number of studies have reported that synergism between CMGs is one of the most important factors influencing CMD severity (Pita *et al.*, 2001; Fondong *et al.*, 2000; Harrison *et al.*, 1997). These studies have shown that mixed infections result in more severe symptoms than single infections. For example, this phenomenon was reported to be of primary importance for the emergence of new geminivirus diseases and a key factor in the genesis and spread of the CMD epidemic in East Africa that started in Uganda (Legg, 1999). The spread of CMD is also influenced by other factors such as which cassava varieties are used, the proximity of other fields, the source of inoculums, crop density and virus strains present (Mabasa, 2007).

The geographical overlap of *Geminivirus* distributions throughout cassava growing areas, aided by the trafficking of planting materials across borders resulting from population movements and trade, provides opportunities for synergism between CMGs (Mabasa, 2007). A number of synergistic interactions have been reported amongst CMGs. Such synergistic interactions were first reported in Uganda and neighbouring countries where a mixed infection of ACMV and EACMV resulted in a severe form of CMD (Harrison *et al.*, 1997; Legg, 1999; Pita *et al.*, 2001).

5.4 Economic impact of cassava mosaic disease

There are great differences between regions in the overall prevalence of CMD and in the severity of the losses caused by it. Various studies have attempted to quantify the impacts of CMD in terms of cassava yield losses. The results show a wide divergence of yield loss estimates attributed to CMD ranging from insignificant to 95 percent. This difference can mainly be explained by the range of cultivars used and the environmental conditions of trial sites (Thresh *et al.*, 1994a). Various factors explain the variations in results; these include the susceptibility of the variety, the stage of crop growth at which infection occurred, the severity of the virus or virus mixture causing the infection, and the abiotic environmental conditions (Fauquet and Fargette 1993; Fargette *et al.*, 1988).

The overall impact of CMD depends on both the loss attributed to infection and the incidence of infected plants (Legg and Thresh, 2003). Fargette *et al.*, (1988) estimated continent-wide cassava yield losses attributed to CMD based on an average yield loss of 37 percent for a local variety in Côte d'Ivoire. However, the limitation of the study was that it assumed that all plants were affected. Pointing out the Fargette *et al.*, 1988 study limitation, Thresh *et al.* (1997) estimated the overall yield loss due to CMD in Africa using a conservative estimate for an incidence of 50 to 60 percent based on the survey data from eight countries and assuming a yield loss of 30 to 40 percent for affected plants. Based on these assumptions, Africa-wide yield losses attributed to CMD were estimated to be 15 to 24 percent which is equivalent to 12 to 23 million tonnes in relation to the actual production at the time, namely 73 million tonnes.

Additional incidence and yield loss data has since become available, particularly for each of the top ten cassava producing countries in Africa excluding Angola (Legg and Thresh, 2003). Legg and Thresh (2003) used a similar approach to update this estimate based on an expanded and updated set of survey data for 17 countries which together represented almost 90 percent of the total African production. Table 5.1 summarises recent CMD incidence data for 16 of the main cassava producing countries in Africa that constitute 90 percent of the total production in the continent.

Table 5.1: Surveys of the incidence of cassava mosaic disease in 18 African countries

Country	Year	CMD incidences (%)	Production 2002 m/t
Uganda	1990-1992	57	
Uganda	1994	65	
Uganda	1997	68	5.27
Chad	1992	40	0.31
Malawi	1992	21	
Malawi	1998	42	1.54
Tanzania	1993	26	
Tanzania	1998	34	5.65
Ghana	1993-1994	72	
Ghana	1998	71	8.97
Benin	1994	53	
Benin	1998	36	2.45
Cameroon	1994	67	
Cameroon	1998	62	1.70
Nigeria	1994	55	
Nigeria	1994	82	
Nigeria	1998	56	33.56
Zambia	1995-1996	41	0.95
Zanzibar	1998	71	NA
South Africa	1998	31	<0.01
Madagascar	1998	47	2.23
Mozambique	1999-2000	20	5.36
Rwanda	2001	30	0.69
DRC	2002	60	14.93
Congo Rep.	2002	79	0.85
Guinea	2003	63	1.00
Conakry	1993	20	
Kenya	1996	56	
(Western)	1998	84	
(Western)	2000	58	
(Western)	1998	51	0.95
Kenya (Coastal)		50	10.60
Other		50	97.01

Source: Legg and Thresh (2003)

The FAO (2003b) calculated "lost" production estimates for each of the 16 countries using the FAO's production estimates, CMD incidence and the 30 to 40 percent range of yield loss used by Thresh *et al.* (1997). For the remaining 10 percent of production for which incidence figures were not available, the average incidence of 50 percent for the other 16 countries was used. Based on these assumptions cassava yield losses attributable to CMD were 19 to 27 million tonnes, based on the current (CMD affected) production total of 97 million tonnes (FAO, 2003b). The results were closely approximated the earlier results by Thresh *et al.* (1997), relative to the respective total production figures for the different dates. The results emphasise the magnitude of the problem that CMD continues to pose to all those with a stake in cassava in Africa (Legg and Thresh, 2003).

Various other regional studies have estimated cassava yield losses attributed to CMD based on survey data combined with yield loss approximations most notably for the pandemic-affected area of East Africa (Legg and Okao-Okuja, 1999). Based on the assumption of a 40 percent yield loss in pandemic-affected areas, a 13 percent yield loss in unaffected areas (Sserubombwe, 1998) and a value for cassava of $100 per tonne, the total monetary losses in pandemic-affected areas of Uganda and Kenya were estimated to be $74 million and those in areas of Kenya and Tanzania which were unaffected at that time were estimated to be $19 million.

Owor (2003) estimated losses attributable to specific viruses and virus mixtures quantifying losses for a single CMD susceptible variety. Although a mild strain of EACMV-Ug2 gave only minor yield reductions in comparison with healthy controls, losses of up to 87 percent were recorded for mixed ACMV and EAMCV-Ug2 infections (Legg and Thresh, 2003).

The estimates indicate that CMD is significantly affecting cassava production on the continent to such an extent that it results in the ineffective use of land, labour and resources, and a decrease in food security. Sseruwagi *et al.*, (2004) argued that controlling CMD would greatly increase productivity, release land and labour for other crops and permit extended periods of fallow to restore soil fertility.

5.5 Cassava mosaic disease and opportunities for genetically modified cassava in South Africa

Berry and Rey (2001) have shown evidence of the occurrence of several CMG species (such as ACMV, ACMV-Ug, EACMV and SACMV) in six southern African countries (South Africa, Swaziland, Mozambique, Angola, Zambia and Zimbabwe). Investigations into the genetic diversity of CMGs in South Africa have revealed the presence of four distinct CMGs: ACMV, EACMV, EACMV-Ug and SACMV (Berry and Rey., 2001; Berrie *et al.*, 1998). Mabasa (2007) indicated the presence of both ACMV and EACMV mostly in mixed infections.

A number of studies have been conducted in South Africa on the epidemiology of CMD (Mabasa, 2007; Berry and Rey, 2001; Jericho *et al.*, 1999; Trench and Martin, 1985). Trench and Martin (1985) confirmed the presence of CMD in South Africa and showed that the principal mode of CMG transmission in South Africa was through stem cuttings. Berry and Rey (2001) conducted a survey of the viruses present and their genetic variation. Jericho *et al.* (1999) provided the first quantitative record of CMD in South Africa in terms of incidence and severity and went further to assess other cassava pests.

Jericho *et al.* (1999) and Berry and Rey (2001) conducted the first studies on the diversity of CMGs in South Africa. It was clear from the studies that CMGs were diverse in South Africa, with a total of four different species found with mixed infections being a common occurrence. Mabasa (2007) argued that this situation presents an opportunity for recombination and synergistic interactions among viruses and that the virus population could be more diverse than is realised. If this is the case, there could be a potentially epidemic situation especially if the current interest in cassava in South Africa leads to the intensification and extensive cultivation of cassava (Mabasa, 2007). It would be necessary to intensify research efforts in designing resistant varieties and therefore GM cassava varieties have a good chance of being adopted.

A number of studies have reported that the disease situation in South Africa is stable (Mabasa, 2007; Jericho *et al.*, 1999; Trench and Martin, 1985). However, Mabasa (2007) argued that the situation could change if the current interest in cassava in South Africa results in the intensification of cultivation. In South Africa there is a growing industrial interest in cassava for the production of starch and biofuels. The use of cultural control practices such as phytosanitation and resistant cultivars could greatly improve cassava production in South Africa (Mabasa, 2007).

Cassava mosaic geminiviruses are transmitted in a consistent manner by the whitefly *B. tabaci* (Brown, Frohlich and Rosell, 1995; Dubern, 1994). The primary source of CMD dissemination is through the stem cuttings used as planting material. Most of the planting materials in South Africa are obtained locally or are bought from Mozambican migrant workers. However, the repeated use of local planting material, most of which is already infected, could result in the deterioration of crop quality. In addition, the supply of planting materials from neighbouring countries could lead to the introduction of new virus strains that may possibly be more virulent than local versions (Mabasa, 2007).

The opening of South Africa's political and economic barriers since the mid 1990s with increased movement of people across borders could present an opportunity for the introduction of new virus strains and species. The growing realisation of the commercial value of cassava in South Africa could lead to the intensification of cassava cultivation. The adoption of GM cassava that is CMV resistant and thus CMD free could help farmers guard against potential crop losses from possible epidemics and other problems that may arise from intensification.

Mabasa (2007) argued that the fact that since there is only one predominant cultivar (locally known as Munyaca) in South Africa, its continuous use could pose a threat to the crop should a more virulent strain or species emerge due to recombination or introduction into the area unless there are interventions. These could take the form of resistant cultivars and practicing phytosanitation. Furthermore, Mabasa asserted that although phytosanitation would be effective in controlling CMD it may become ineffective if cassava cultivation is intensified which could lead to an abundance of whiteflies. This was evident in the commercial farm in Barberton where some fields were entirely infected and whiteflies were present in large numbers (Mabasa, 2007). These observations favour the need to encourage the use of resistant cultivars such as GM cassava varieties that are resistant to CMV.

5.6 Gross margin analysis for cassava, maize and potato

Table 5.2 presents the gross margin analysis of cassava, maize and potato under irrigation while Table 5.3 presents the gross margin analysis of cassava and maize under dryland conditions, given that cassava can replace maize production in marginal lands because cassava is a crop that thrive better under these conditions compared to maize. The potato gross margin was left out under dryland conditions because dryland potato production in South Africa is relatively low. The results are based on data obtained from various sources: the CSM, the ARC Institute for Industrial Crops, Potato South Africa, Tongaat Hullet Group and BFAP. There was limited information on cassava production data compared to other crops.

The most important and common variables were selected for the three crops. The prices are pegged at farm gate prices on raw materials of the crop. It should be noted that the seed price for cassava under irrigation (R2 000) is an estimation which assumes that the farmer is breeding and managing the cuttings on his own. If GM cassava is introduced the seed price of cassava is likely to increase close to that of potatoes (R21 400) under the assumption that there will be costs involved in testing, certifying and treating the cuttings. The costs of cassava inputs under irrigation (fertiliser, fuel and labour) were also based on the costs of potato inputs. The justification was that there was limited production data on cassava and experts at CSM advised that the cassava production costs are closely related to those of potatoes. The starch prices of maize and cassava were sourced from Tongaat Hullet and CSM. The first percentages of starch per tonne were also sourced from Tongaat Hullet and CSM but the others were assumptions made because amylose free cassava is likely to have higher starch levels (Tongaat Hullet 2008; Casey, 2008).

Gross margin results per hectare show that cassava production (-R9, 265) is the least profitable and negative under irrigation compared to maize (R9 760) and potato (R43 180). Although cassava has a negative gross margin it has lower variable costs (R24 565) compared to the double costs of potato and maize (R46 240). This shows that cassava is a lower risk crop to produce compared to potatoes and if anything goes wrong the farmer does not lose a great deal of money.

One should also bear in mind that cassava is a crop that can recover from diseases, unlike potatoes which when a field is affected by diseases may be wiped out if no action is taken early.

However, the processing of cassava into starch yields 13.5 tonnes compared to about 6 tonnes from both maize and potato. Regardless of the starch processing costs and holding all other elements remaining constant, cassava yields the highest income from starch per hectare (R74 250) compared to maize (R29 514) and potato (R32 400). The results may explain some of the reasons why the cassava starch factory opened by African Products in South Africa closed down in the 1980s. It is evident that farmers do not make profits from selling raw cassava output while processors make huge profits. This is argued to have prompted farmers to shift away from cassava production and to grow timber and sugarcane which were profitable hence no supplies of cassava to the company. An analysis must be done on market opportunities for farmers as well as on including them in the processing chain of the crop.

Table 5.2: Gross margin analysis for cassava, maize and potato under irrigation

Cassava		Maize		Potato	
Yield/ha	**45 tonnes**	**Yield/ha**	**10 tonnes**	**Yield/ha**	**45 tonnes**
Income @ R340/tonne	**R15 300**	**Income @ R1600/tonne**	**R16 000**	**Income @ R2000/tonne**	**R90 000**
Selected directly allocated cost		**Selected directly allocated cost**		**Selected directly allocated cost**	
Seed/planting material	R2 000	Seed/planting material	R1 450	Seed/planting material	R21 400
Fertiliser (including gypsum & micro elements)	R14 700	Fertiliser & lime	R3 700	Fertiliser (including gypsum & micro elements)	R14 700
Fuel	R2 145	Fuel	R600	Fuel	R2 145
Herbicides	R365	Herbicides	R350	Herbicides	R365
Insecticides and fungicides	R2 855	Insecticides and fungicides	R100	Insecticides and fungicides	R5 710
Seasonal labour	R2 500	Seasonal labour	R40	Seasonal labour	R2 500
Total selected variable costs	**R24 565**	**Total selected variable costs**	**R6 240**	**Total selected variable costs**	**R46 820**
Gross margin	**-R9 265**	**Gross margin**	**R9 760**	**Gross margin**	**R43 180**
Percentage of starch/tonne	**30%**	**Percentage of starch/tonne**	**60%**	**Percentage of starch/tonne**	**14.40%**
Starch yield t/ha	**13.5**	**Starch yield t/ha**	**6**	**Starch yield t/ha**	**6.48**
Income from starch @ R5500/tonne	**R74 250**	**Income from starch @ R4919/tonne**	**R29 514**	**Income from starch @ R5000/tonne**	**R32 400**

Sources: CSM (2008), ARC (2009), BFAP (2009) Potato South Africa 2009/2010 Limpopo production season and Tongaat Hullet Group (2009)

Table 5.3: Gross margin analysis for cassava and maize under dryland conditions

Cassava		Maize	
Yield/ha	**25tonnes**	**Yield/ha**	**4tonnes**
Income @ R340/tonne	**R8 500**	**Income @ R1600/tonne**	**R6 400**
Selected directly allocated cost		**Selected directly allocated cost**	
Seed/planting material	R1 000	Seed/planting material	R600
Fertiliser (including gypsum & micro elements)	R7 350	Fertiliser & lime	R3 000
Fuel	R1 437	Fuel	R750
Herbicides	R244.55	Herbicides	R330
Insecticides and fungicides	R1 427.50	Insecticides and fungicides	R100
Seasonal labour	R1 675	Seasonal labour	R40
Total costs	**R13 134.20**	**Total costs**	**R4 820**
Gross margin	**-R4 634.20**	**Gross margin**	**R1 580**
Percentage of starch/tonne	**30%**	**Percentage of starch/tonne**	**60%**
Starch yield t/ha	**7.5**	**Starch yield t/ha**	**2.4**
Income from starch @ R5500/tonne	**R41 250**	**Income from starch @ R4919/tonne**	**R11 806**

Sources: CSM (2009) and BFAP (2009)

Under dryland conditions cassava still has a negative gross margin per hectare compared to maize. The analysis of starch production again shows that cassava yields the highest returns compared to maize. Again, cassava is the highest starch yielder per area and it is clear that cassava production on dryland can be a good source of income for small scale farmers if they are involved in the processing of the starch. This will make cassava production more profitable than maize production.

If farmers adopt GM cassava that is amylose free they may earn an increased income because of the higher prices related to the improved starch quality. Table 5.4 below presents the gross margin analysis of GM cassava (CMV resistant and amylose free) and various scenarios of CMV infection.

Table 5.4: Gross margin analysis of GM cassava (CMV resistant and amylose free) and infected cassava

Percentage yield losses	**0% yield loss**	**10% yield loss**	**20% yield loss**	**40% yield loss**
Yield/ha	**45tonnes**	**40.5 tonnes**	**36 tonnes**	**27 tonnes**
Income @ R340/tonne	**R15 300**	**R13 770**	**R12 240**	**R9 180**
Selected directly allocated cost				
Seed/planting material	R2 000	R2 000	R2 000	R2 000
Fertiliser (including gypsum & micro elements)	R14 700	R14 700	R14 700	R14 700
Fuel	R2 145	R2 145	R2 145	R2 145
Herbicides	R365	R365	R365	R365
Insecticides and fungicides	R2 855	R2 855	R2 855	R2 855
Seasonal labour	R2 500	R2 500	R2 500	R2 500
Total selected variable costs	**R24 565**	**R24 565**	**R24 565**	**R24 565**
Gross margin	**-R9 265**	**-R10 795**	**-R12 325**	**-R15 385**
Percentage of starch/tonne	**30%**	**30%**	**30%**	**30%**
Starch yield t/ha	13.5	12.15	10.8	8.1
Income from starch @ R5500/tonne	R74 250	R66 825	R59 400	R44 550
Income from amylase free starch @6325/tonne at 15% price increase	R85 387.50	R76 848.75	R68 310	R51 232.50
Income from amylase free starch @6600/tonne at 20% price increase	R89 100	R80 190	R71 280	R53 460
Income from amylase free starch @7700/tonne at 40% price increase	R103 950	R93 555	R83 160	R62 370
Income from amylose free starch @8800/tonne at 60% price increase	R118 800	R106 920	R95 040	R71 280

Assuming that in the first year a farmer uses clean cuttings of cassava without adopting GM cassava that is virus resistant and amylose free the crop may yield 45 tonnes per hectare and 13.5 tonnes of starch. As indicated in the above sections, the economic loss due to CMV ranges between 30 and 40 percent (Legg and Thresh, 2003). If a farmer does not use new cuttings, but uses cuttings from the previous season there is a 10 percent chance that the cuttings will be affected by the virus. The yield will decrease from 45t/ha to 40.5t/ha and at the same time the gross margin will decrease to -R10 795, starch yields will decrease to 12.15t/ha and the income from starch will decrease. At a 40 percent yield loss caused by CMV, yields will decline to 27t/ha, the gross margin will decrease to a loss of -R15 385, starch yields will decrease to 8.1t/ha and the income from starch will decrease as well.

Assuming a farmer adopts GM cassava the yields would remain at 45t/ha because the 30 to 40 percent yields loss will be under control due to the new variety. However, the seed price increases to almost the same price as that of potato because GM seeds will in all likelihood have to be tested, treated and certified. Starch yields will be 13.5t/ha amylose free. Since it is of a higher quality, the starch price per tonne may increase from R5500 to R6325 assuming a 15 percent increase in price since amylose free maize is purchased at a 15 percent premium. With this quality related price premium an income of R85 387.50 at 45t/ha of cassava is possible. GM cassava starch is perceived to be of higher quality than that of waxy maize and may fetch an even higher premium of 20%, 40% or 60%. In addition, amylose free starch should also save expenditure on environmentally harmful and expensive processing chemicals. Saving on these chemicals is not included in these calculations, but should play a significant role in price determination and the profitability of processing.

Table 5.5 shows a comparison between different characteristics of cassava, maize and potato. The table show the advantages of cassava in comparison with other starch producing crops.

5.7 The potential and future of GM cassava in South Africa

The above analysis has shown that cassava production is not profitable at the farm level compared to when it is processed into starch. GM cassava that is mosaic virus resistant and amylose free stands a chance of thriving in South Africa and Africa as a whole and will benefit from the rising demand of starch and starch related products. There is also increasing demand for biofuels and biodegradable products in these environmentally aware times. For instance, the use of plastic packaging is decreasing in South Africa creating huge market opportunities for biodegradable packaging made from starch. This creates a big market for cassava starch. The use of ethanol in fuel and as a source of energy in gel stoves in South Africa and Africa will also broaden the market for cassava.

Table 5.5: Comparison between cassava and other starch producing crops

Variable	Crop		
	Cassava	**Maize**	**Potato**
Starch quality	Free from colour and impurities	High lipid content	Lower lipid content than maize
Starch output	High yielding compared to maize and potato Relatively cheap source of raw material containing a high concentration of starch on a dry-matter basis that can surpass the properties offered by other starches (maize and potato)	Lower starch yield per hectare	
Amylose content	17%	28%	20%
Starch adhesives	More viscous and smooth than maize or potato and are easily prepared. Joints have a high tensile strength	Lower tensile strength	Lower tensile strength
Application	Because of low lipid and protein levels cassava starch is considered to have a bland taste Excellent thickening and desirable textural characteristics	Maize starch has a slight cardboard taste in food products	Potato starch is slightly more bitter than cassava starch
Starch processing	Cassava starch is easy to extract using a simple process when compared to other starches. It can be carried out on a small scale with limited capital	Starch extraction done at an industrial level and requires heavy machinery	Starch extraction done on an industrial level internationally
Growing conditions	Cassava can be grown under conditions that are often unsuitable for other crop production Can be grown as a monoculture	Needs favourable soils and climatic conditions Requires rotation	Needs favourable soils and climatic conditions Requires rotation by law
Other starch properties	Higher starch digestibility in animal feeds compared to cereals Minimum or no mycotoxin contamination compared to that of cereals like maize Cassava fed animals have minimum animal waste odour. Field trials have shown that manure of cassava-fed animals stink less than those of animals on cereal diets. Even though the exact reasons for this are not known, the advantage helps to lessen the pollution of animal production units Cassava diets have lower animal production costs, not only through the reduction of feed cost, but also through the reduction in the use of antibiotics and medication in animal production. This advantage is an important factor which farmers should consider	Not well digested in the small intestines of ruminants High content of mycotoxins which are high stressors in animal feeds for breeder animals and ducks	

Source: ARC-Institute of Industrial crops (2009); Casey (2008) and Lehmann and Robin *(2008)*

If GM cassava is successfully produced in South Africa, the country stands a chance of becoming the centre for the multiplication of the cultivar due to more investors investing in cassava production and exporting cassava to other countries. One should bear in mind that cassava is one of the crops that farmers can process into starch at farm level without sophisticated machinery. Therefore, GM cassava will be of great benefit to farmers because they will have a low risk of losing their yield to cassava mosaic virus and at the same time if they process the crop further into starch the amylose free starch will fetch a high price. Based on rough calculations it is clear that cassava and cassava starch have favourable characteristics compared to maize and potato while yielding more starch. The gross margin of cassava may be low, but the total variable costs are also low compared to those of potatoes.

The researchers at ARC Institute for Industrial Crops and CSM (Casey, 2008) argued that cassava has many advantages and it will do very well in South Africa by outperforming other starch producers like maize and potato for a number of reasons:

- Cassava starch is odourless and can therefore blend well with other flavours.
- Cassava starch's properties have preference in the paper industry.
- Enterprise Foods, one of the meat producers in South Africa, uses cassava starch in the binding of sausages and cold meats. The sausages and meats that use cassava starch for binding last six times longer than those that use maize starch binding, reducing the use of preservatives.
- Cassava can be grown as a monoculture crop unlike potato which requires rotation by law.
- The cassava crop does not deplete nutrients in the soil.
- There is more knowledge amongst the breeders about conventional cassava varieties than about cereals.
- There are good cultivars available from well known organisations like the Chartered Institute of Architectural Technologists and the ARC Institute for Industrial Crops.

5.8 Results from interviews on genetically modified cassava

Despite the above opportunities for GM cassava in South Africa, expert interviews raised some concerns on the need for introducing GM cassava that is mosaic virus resistant and amylose free in South Africa. Researchers at the ARC Institute for Industrial Crops emphasised that the traditional breeding processes have brought about a significant resistance to diseases and that there is uncertainty about the cost implications of GM cassava. They further argued that the situation of CMV is stable in South Africa. However, GM cassava may be of great help to Africa when the trials which are awaiting a permit are done. They may determine the future of GM cassava in South Africa and Africa. The argument relating to the low incidence of CMV in South Africa is supported by a number of empirical studies that have shown that CMV is not a major problem in the country with an approximate 2 percent incidence rate (Mabasa, 2007; Jericho *et al.*, 1999; Trench and Martin, 1985). However, one may argue that if the production of cassava increases, the disease prevalence may increase due to the increase in the plant population or due to less well managed propagation conditions.

The managing director of CSM highlighted that their Dendron farm does not suffer from mosaic virus damage. He reported that they have managed to control CMV through good management practices and that they have developed a reliable chemical pesticide to control whiteflies. He further reiterated that CSM is committed to producing the cassava starch their clients prefer and that at this very early stage in the development of the technology there are still many unknowns surrounding GM cassava (Casey, 2008).

The other arguments by the ARC Institute for Industrial Crops of the challenges that may face GM cassava include that:

- Cassava is not a popular crop amongst South Africans like maize, wheat and potato hence there is a need to campaign for conventional cassava amongst farmers and consumers before introducing GM cassava.
- Cassava mosaic virus has proven to be controlled if planting materials are kept clean and through chemical control and the removal of infected plants.
- There is a long process and much bureaucracy involved in applying for the licence for the trial of GM cassava in South Africa implying that it may take a long time before trials can be done in the country. With these constrains in place the future of GM cassava is not clear.

The researchers from the ARC also argued that many farmers (especially subsistence farmers) in South Africa and Africa in general do not see the cassava mosaic virus and disease as a major problem. They reported that farmers actually tend to eat the leaves that are attacked by the cassava mosaic virus because they say the mosaic infected leaves taste better. They further argued that another breeding challenge is that farmers prefer to keep their own infected planting material making it difficult to keep materials virus free in smallholder farms. These are other likely challenges which will face the introduction of GM cassava as many farmers repeat their planting material and the new variety may lose its resistance over time (ARC Institute for Industrial crops 2009).

The researchers also argued that cassava mosaic virus can be controlled by natural and traditional methods if the planting material is kept clean. They further indicated that if symptoms of the cassava mosaic disease appear they can be controlled by rouging. They emphasised that natural selection is giving good results in controlling the mosaic virus therefore the GM line may be unnecessary and probably quite expensive. The other major concerns relate to the slow progress in the application of trial permits in South Africa and the consumer acceptability of the GM cassava which requires careful assessment. In addition, lack of capacity, movement and the resignation of people in the related government offices for permit applications is another frustrating problem in the application for the license. They also argued that breeding against the resistance of the mosaic virus needs to be done according to the intensity of the disease pressure and that there are many different types of mosaic viruses with different effects which might necessitate the production of many different lines of cultivars according to areas and virus type which would add additional expenses to the process.

The researchers at ARC Institute of Industrial Crops also mentioned the case of GM cassava virus-resistant varieties discovered by the Danforth Centre in 2006 where the varieties developed seven years before had lost resistance to the African cassava mosaic virus. This adds to the negative perception on the viability of GM cassava for government, breeders and farmers, reducing the likelihood of the adoption of this, probably incorrectly perceived to be unpredictable, technology.

They further stressed that the trials that failed in Kenya have made the South African government lose faith in GM cassava and a lot of work will have to be done to defend the introduction of GM cassava and conduct trials in South Africa. However, the application is still in progress since an appeal was submitted and they are still waiting for the response.

Breeders argued that whiteflies (the vector transmitting cassava mosaic disease) are not a big problem in most parts of South Africa because of the dry conditions compared to the humid areas of some African countries. They indicated that, even if the virus resistant GM cassava is introduced, chemicals may still be needed to control other insects like the mealie bug.

The reseachers also argued that there may be no need for GM cassava that is amylose free as there are already mutant local varieties with very low amylose content. These arguments are supported by empirical findings reported by Ceballos *et al.* (2007) regarding the discovery of an amylose free starch mutant in conventional cassava. The mutant variety is a cheaper option than developing a GM variety thereby making it unnecessarily expensive to breed an amylose free GM cassava. They also argued that cassava starch without amylose is not good for human consumption purposes because foods that have starch with amylose also have a number of health benefits which include better bowel health, preventing colorectal cancer and improving the control of blood glucose, which can help manage diabetes and reduce obesity. This implies that amylose free cassava may have only have a niche market in the food, paper and textile industry.

Based on the arguments and constraints discussed above, it is clear that there are some challenges for the introduction of GM cassava to South Africa. It is evident that cassava breeders, cassava starch manufacturers and users have some concerns regarding GM cassava. This study therefore recommends that successful cassava production and commercial utilisation should focus on the conventional varieties while awaiting the field trial permit.

5.9 Summary

This chapter discussed the impacts of the cassava mosaic virus and the opportunities for genetically modified cassava that is resistant to the cassava mosaic virus and disease in South Africa. There are many differences between regions in the overall prevalence of CMD and in the severity of the losses caused. Empirical results show a wide divergence of yield loss estimates attributed to CMD ranging from insignificant to 95 percent. This difference can mainly be explained by the range of cultivars used and the environmental conditions of trial sites.

For the purpose of this study and due to available data, a simple analysis was applied to analyse the economic profitability of genetically modified cassava in South Africa in comparison with maize and potato. The results show that cassava production is not profitable at the farm level for either dryland or irrigation scenarios. However, processing cassava into starch results in higher returns from the higher starch output and quality compared to potato and maize. The starch from cassava has many industrial applications as was discussed in Chapter 4. The scenario analysis for GM cassava and infected cassava at 10%, 20%, 30% and 40% expected yield loss showed that the CMV resistant and amylose free GM cassava provides additional benefits due to their better quality and higher starch yields compared to infected varieties. The higher quality starch yields a higher profit making it even more profitable to produce cassava for starch.

It is evident from interview discussions that there are challenges for GM cassava in South Africa. Although CMV is one of the major contributing factors to low cassava yields in Africa, empirical studies in South Africa have shown that the situation in the country is very low with an approximate 2 percent incidence. In addition, interview results showed that CMV has been controlled through good management practices, natural selection and chemical control. Although GM cassava is assumed to produce better starch quality that is amylose free, results from the study show that there are mutant varieties of conventional cassava varieties that can produce better quality starch with very low amylose content. The latter tend to be less time consuming and less expensive compared to GM cassava which is still awaiting trials.

Cassava is not a popular crop in South Africa compared to maize and other starch cereals like potatoes. Also, GM cassava is surrounded by many uncertainties that still need empirical case studies to debunk them as discussed above. However, there is growing interest in cassava starch in commercial industries and this presents a good opportunity for supporting and promoting conventional cassava in preparation for the coming of GM cassava. In addition, results show that cassava starch has many advantages over starches from cereal crops like maize. The study therefore recommends that successful cassava production and commercial utilisation should focus on development and propagation of conventional varieties to boost the local cassava industry.

CHAPTER 6

Summary, conclusions and implications for policy and research

6.1 Summary

The main objective of this study was to evaluate the economic potential and opportunities for introducing GM cassava that is CMV resistant and produces a higher quality starch (amylose free) in South Africa. Cassava production in South Africa is not significant and thus a study on a new technology for this may crop seem strange. However, with new genetically modified technologies cassava production in South Africa can become more viable and valuable than other competing crops like maize and potatoes, as the new technology addresses the vital production limitations of the cassava mosaic virus and delivers a more valuable high quality starch product (amylose free cassava starch). For the genetically modified cassava to gain the institutional support for commercialisation it is necessary to carry out an ex ante assessment of the economic potential and opportunities of the intervention.

Various ex ante economic methods and approaches to assessing economic impacts exist in the subject literature: the partial budget approach, cost benefit analysis, consumer and producer or economic surplus approach and the computable general equilibrium or simulation model. For the purpose of this study and due to available data, a simple gross margin analysis was applied to analyse the economic profitability of genetically modified cassava in South Africa in comparison to maize and potato. Due to data limitations, this study relied on a synthesis between secondary information from various studies in other African countries and interviews with experts. The information collected was used to assess the potential for genetically modified cassava in South Africa. Secondary information and interviews with experts were used to provide more insights and information relating to the possible opportunities, constraints, performance of the genetically modified events, and production practices for cassava and other competing crops like maize and potato in the country.

Cassava has a number of important traits that present a competitive advantage for cassava as a commercial crop for farmers that is comparable to other crops such as maize and potatoes. For example, cassava can be grown in difficult environmental conditions and has a wide range of applications ranging from food products to industrial starches. Cassava can be grown as a monoculture crop unlike maize and potatoes which require rotation. In addition, the special characteristics of cassava starch present an important alternative to maize, wheat, rice and potato. Cassava flour and starch have unique properties which make them ideal for many applications in the food, textile and paper industries where flour and starch from the other crops have a quasi monopoly. For example, among starch producing plants, cassava has been considered as the highest producer of starch (25 to 40 percent higher than rice and maize) and as the most efficient (the highest) converter of solar energy to carbohydrate per unit area.

Despite these advantages, cassava has remained a neglected crop in South African agricultural research and development activities compared to cereals. However, the increasing demand for starch based applications in the food industry and industrial sector and the fact that industry is searching for a cheaper substitute to cereals presents an impressive market growth potential for cassava starch. For example, the paper industry, food industry and others including the textile industry are the main buyers of cassava starch in South Africa.

The gross margin analysis results showed that cassava production is not profitable at farm level for both dryland and irrigation scenarios. However, processing cassava into starch resulted in higher returns from the higher starch output and quality compared to potato and maize. The starch from cassava has many industrial applications as was discussed in Chapter 4. The scenario analysis for GM cassava and infected cassava at 10%, 20%, 30% and 40% expected yield loss showed that the CMV resistant and amylose free GM cassava provides additional benefits due to its better quality and higher starch yields compared to infected varieties. The higher quality starch yields a higher profit making it even more profitable to produce cassava for starch.

6.2 Conclusion

The results of interviews with subject experts show that cassava production and utilisation has lagged behind other crops in South Africa and the crop is sparingly and informally traded. An analysis of market constraints showed that there is a strong consumer taste preference for maize and other cereals dominating the starch market. Other factors that have contributed to the lagging behind of cassava in South Africa and other African countries are the post colonial government policies that favoured maize over cassava.

The results from interview discussions show that there are some concerns and questions related to the introduction of GM cassava in South Africa. One of the main concerns was that empirical studies in South Africa have shown that the occurrence of cassava mosaic virus in the country is very low; it has an approximate 2 percent incidence rate. As a result, large scale producers have been able to control CMV through good management practices, natural selection and chemical control. Also, bureaucracy and lack of transparency in the South African GMO regulatory system, especially regarding socio-economic issues, may result in an extended delay before contained field trials can be conducted in the country. It has also become clear that the two proposed GM events are still relatively far from being commercialisable. Furthermore, the current availability of mutant varieties of conventional cassava varieties that can produce better quality starch with a very low amylose content provide an important alternative to GM cassava. The utilisation of the former tends to be less time consuming and less expensive compared to GM cassava.

6.3 Recommendations

It is difficult to perform a socio-economic assessment before confined laboratory tests or field trials have been conducted. Further development of the potential product would supply crucial information that is needed for an ex ante socio-economic study. It is clear that this study was conducted far too early as GM technologies are not yet remotely close to being ready for commercialisation. Many basic researches still need to be conducted, including field trials. The South African GMO Act and regulations do not clearly stipulate when a socio-economic study should be conducted, but it is clear that the worth of a study conducted before any confined field trials had been performed would be questionable.

For the purpose of this study and due to available data, a simple analysis was applied to analyse the economic profitability of genetically modified cassava in South Africa in comparison with maize and potato. The results show that cassava production is not profitable at the farm level for either dryland or irrigation scenarios. However, processing cassava into starch results in higher returns from the higher starch output and quality compared to potato and maize. The scenario analysis for GM cassava and infected cassava at 10%, 20%, 30% and 40% expected yield loss showed that the CMV resistant and amylose free GM cassava provides additional benefits. The higher quality starch yields a higher profit making it even more profitable to produce cassava for starch.

It should also be noted that farmer education on CMD should be done before the introduction of the GM cassava in most parts of Africa because farmers have learnt to live with the disease. Some farmers no longer see CMV as a problem, but consume the virus affected leaves with relish. If a trial is done in such an area it will help to assess whether GM cassava will stand the high risks of losing its resistance in the high disease prone areas.

6.4 Limitations of the study and areas for further research

This study has certain limitations that should be borne in mind. First, there is lack of data on the South African cassava sub-sector because the study done was based on a request on a topic with limited information in South Africa. For example, organisation that deal with crops like the Institute for Industrial Crops at ARC have limited information on cassava production in South Africa, especially in the smallholder sector due to the fact that cassava production is not popular compared to maize and potato. It should be noted that production of was once neglected in the eighties because it was not profitable to farmers because they had to sell the crop at a low price hence there is limited information on cassava production in South Africa. The gross margins of cassava were constructed using values of the potato gross margin (secondary data) and the price of cassava seed under irrigation was estimated because there was an assumption that the farmer would use his own planting material. None of the empirical models used in ex ante analyses could be implemented due to a lack of data. Some of the people contacted were not willing to disclose their information due to confidentiality clauses and there is no recorded information in the smallholder cassava sector in the country. It should be noted that the cassava industry in South Africa has only one player which makes it difficult to get information if the player fears competition. It is imperative that future research focuses on collating available information in the cassava sub-sector in the country including the willingness of farmers to adopt GM cassava to allow a detailed analysis of the sector. Once this is done it should allow for a detailed comparative analysis of the cassava sector with other cereal starch crops like maize and potatoes.

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