**Review**

**Cassava Biotechnology, a southern African Perspective**

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The pre-requisite for any cassava (Manihot esculenta Crantz) transformation program that proposes to develop improved plants is the availability of a reliable regeneration system. Presently many laboratories that prioritize cassava research are able to reliably regenerate plants from a range of cultivars. Unfortunately, some cultivars are still either recalcitrant or resisting attempts to induce useful levels of embryogenesis from their tissues. The review gives a brief account on the different uses of cassava, its introduction into southern Africa and the region's current cassava disease complex with a particular focus in South Africa. Different cassava regeneration and gene transfer systems are also discussed. We conclude by presenting future prospects in southern African cassava biotechnology.

**Key words:** Cassava, CMD, Cassava biotechnology.

**INTRODUCTION**

This review focuses on a brief account on the different uses of cassava, its introduction into southern Africa and the region's current cassava disease complex with a particular focus on South Africa is examined. We will also discuss the different cassava regeneration and gene transfer systems currently residing within five laboratories in Europe and America forming an advanced cassava transformation group. Those laboratories are ILTAB, CIAT, ETH, Ohio State University and Wageningen University. We will conclude by sharing future prospects in cassava biotechnology in order to make the technology more widely applicable in the southern African region.

Cassava (Manihot esculenta Crantz) is a vegetatively propagated root crop used as a staple throughout the tropics and sub tropics. It is the fourth most important and cheapest staple food crop after rice, wheat and maize in developing countries, providing food for over 600 million people (Schöpke *et al*., 1993a). Cassava, otherwise known as tapioca, yucca, manioc or mandioca is an outcrossing, monecious member of the family Euphorbiaceae. Considered as allopolyploid (2n=36), it is a highly heterozygous, semi-woody, perennial shrub varying from 1-4 m in height depending on the cultivar, and produces between 3 and 36 storage roots per plant. Storage roots on a fresh mass basis contain between 20% and 36% starch and approximately 77% on a dry mass basis (Gray, 2003). Cassava is propagated vegetatively usually via lignified stem cuttings. After planting, new roots are produced and axillary buds sprout to form the shoot system. About two months later, photosynthates produced by the established leaf canopy are diverted to root system where the excess energy is converted to starch and stored in the parenchyma of greatly thickened storage roots, generally referred to as tubers. It can also be cultivated in association with several other crops in most African countries, as discussed by Nweke (1994).

Although still a subject of debate, its centre of origin is generally believed to be southern border of the Amazon basin (Allem, 2002). It was introduced into Africa in the Congo River delta by the Portuguese in the 15th century (Jones, 1959), and its cultivation spread rapidly to many agro-ecologies including East Africa through Madagascar and Zanzibar and later to Asia. Cassava was introduced into Mozambique by the Portuguese in the 17th century, and was adopted as a food crop by the Tonga tribesmen, in eastern Transvaal now Mpumalanga Province, Swaziland and northern Natal (Daphne, 1980). Cultivation of cassava by neighbouring tribes started gradually and it appeared, therefore, that the cultivation of cassava in SA was related to the major tribal movements of the 1830s and 1860s (Daphne, 1980). Cultivation continued to increase throughout the 20th century, most noticeably in Africa where colonial powers often encouraged its cultivation as a famine reserve.

Large scale cassava production in SA was impaired by a taste preference for maize, but in the late 1970s there was a renewed interest in cassava, and extensive yield trials were conducted throughout sub-tropical regions of

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Kwazulu-Natal Province and Northern Province (now called Limpopo Province) under a range of environments (Daphne, 1980). In Mozambique, cassava is the second most important staple food after maize, which more than 50% of the population depend on. The crop plays a big role as a food security crop, and is mostly produced through subsistence farming. It is grown mostly in the northern and coastal regions of the country. The main cassava production provinces are Nampula, Zambézia, Cabo Delgado and Inhambane. Across the country, roots are eaten fresh or dried (flour), and leaves as a vegetable. Yields in Mozambique are consistently low (8-9 tonnes per hectare) compared with yield potential of 70 ton/ha (FAO, 2003). Low yields are attributed to both abiotic and biotic factors.

Cassava is widely consumed as a porridge, which is prepared from dried and pounded roots, but eaten in a very wide range of forms in different parts of the African continent. Cassava is reported to be consumed in 28 different forms in Cameroon, alone (Kokora Nicole, pers. comm., 2002). In SA, there are a number of cassava-processing methods consisting of drying and pounding of the roots to produce porridge known as ‘Xigema’, and cooking of leaves to produce a condiment known as ‘Mathapit’ (Diana Sikulane pers. comm. 2002). Cassava is also consumed as a snack food in various parts of the continent. Varieties used as snack food are ‘sweet’ types, low in cyanic acid, which can be boiled and eaten or even consumed raw. In certain regions, the leaves, which contain appreciable quantities of protein and vitamins, are used as a major component of the diet to provide supplementary protein, vitamins and minerals to complement the carbohydrate rich staple (Lacanster and Brooks, 1983).

CASSAVA DISEASE COMPLEX IN SOUTHERN AFRICA

The most important diseases affecting cassava production in Southern Africa are Cassava brown streak disease (CBSD) and Cassava mosaic disease (CMD). CBSD is caused by cassava brown streak virus (CBSV) while CMD is caused by several whitefly-transmitted begomoviruses. Both diseases cause enormous losses to cassava production. In Mozambique, CBSD was reported for the first time in 1997 when farmers were reporting major losses of cassava caused by root rotting, which by 1998 were considerable, and had infected large areas of coastal Nampula province in the northern part of the country. As a result many farmers started to turn to alternative crops. Farmers in Zambézia Province, south of Nampula, also had the same problem of cassava root rotting. A survey carried out by Natural Resources Institute (NRI) in 1999 in the affected areas of Nampula, Zambézia and Cabo Delgado Provinces identified the disease as caused by CBSV. CBSD is still confined to the north of the country, mainly in the coastal regions.

A study was conducted by Berry and Rey (2001) in six countries in southern Africa, namely Angola, Mozambique, South Africa, Swaziland, Zambia and Zimbabwe. It was found that African cassava mosaic virus (ACMV) occurred in five of the six countries (except Angola), East African cassava mosaic virus (EACMV) was present in five countries (except Zambia) and South Africa cassava mosaic virus SACMV) was detected only in South Africa and Swaziland. In addition, their report for the first time in southern Africa implicated the appearance of the Ugandan variant virus (EACMV-Ug), which was found in mixed infections with other cassava-infecting begomoviruses.

There is evidence that mixed infections by cassava mosaic Geminiviruses (CMGs) are more damaging than single infections, as reported in studies in Uganda and Cameroon (Fondong et al., 2000; Pita et al., 2001). Symptom severity is associated with the magnitude of yield loss (Thresh et al., 1994) and some yield loss models are derived from the relationships between disease severity and disease incidence.

CMGs are disseminated in the stem cuttings used routinely for vegetative propagation. They are also transmitted by the whitefly, Bemisia tabaci Gennadius. Dissemination by stem cuttings accounts for the occurrence of the disease in areas where there is little or no spread by the whitefly vector (Calvert and Thresh, 2002). The distribution of immigrant whiteflies and of plants newly affected by CMD is influenced by the direction of the prevailing wind and by the effects of wind turbulence around and within stands. The incidence of whiteflies and CMD is highest at the crop margins, especially along the windward and leeward edges and environmental gradients have been observed when whitefly populations decrease with increasing distance from the field boundaries. Incidence is also increased by breaks or discontinuities in the crop canopy, which facilitate the alighting and establishment of viruliferous vectors (Calvert and Thresh, 2002).

Obvious benefits are realised by decreasing the losses caused by CMD and this can be achieved by a reduction in the incidence and/or severity of the disease. Various approaches to control are possible, however, the main attention has been given to the use of resistant varieties and phytosanitation, involving the use of CMD-free planting material and the removal (rouging) of any additional diseased plants that occur (Legg and Thresh, 2003). Farmers occasionally use insecticides in attempts to restrict the spread of CMD by controlling the whitefly vector. However, the use of insecticides on cassava or other tropical crops has received little attention from researchers in Africa and this approach is unlikely to be effective. It is also inappropriate considering the costs that are involved and the risk to farmers, consumers and the environment (Calvert and Thresh, 2002).
Reported losses, as indicated by evidence, are more qualitative than quantitative. Trials to assess the effect of CMD on cassava yield have provided differing results ranging from virtually no loss to almost total loss (Thresh et al., 1994).

**GENETIC ENGINEERING OF CASSAVA**

Biotechnology is fast proving to be a valuable tool for genetic improvement of plants. However, the prerequisites for efficient exploitation of biotechnology are the development of reliable transformation systems, efficient tissue culture regeneration methods, transformation and selection methods of transgenic plants. Genetic engineering is a powerful tool that complements traditional breeding and can extend the genetic pool of useful gene sources beyond the species (Fregene and Puonti-Kaerlas, 2002). Transgene technology also offers the advantage of precisely transferring single or even quantitative traits without the problems of linkage encountered in traditional breeding.

In cassava improvement programs, the limiting factors in production and utilization are among others, inadequate resistance to viruses, bacteria and insect pests difficulties in the production of novel value-added products from cassava, poor starch characteristics, rapid post-harvest deterioration of tubers, and a ubiquitous problem limiting marketability of the crop, which hinders the development of medium to large scale processing centres. Additional problems still unresolved by traditional breeding are, low protein content of cassava products and the presence of cyanogenic compounds in the tubers (Puonti-Kaerlas, 1998).

Conventional breeding for the agronomic improvement of cassava is frustrated by the crop’s inherent heterozygous nature, inbreeding depression and the polygenic and recessive nature of many desirable traits. Therefore, genetic engineering has been identified as a powerful tool to overcome these limitations. Traditional breeding of cassava is difficult as few natural resistance genes have been found in sexually compatible germplasm. The allotetraploid nature of cassava that leads to polymorphisms after crossing, its high outcrossing nature and its low fertility linked to inbreeding depression restrict the use of traditional breeding (Puonti-Kaerlas, 1998).

Genetic engineering, therefore, presents an alternative to traditional plant breeding. Using the techniques of molecular biology, a single gene that codes for a desired trait, such as insect resistance, increased protein content, or tolerance to drought is isolated and then combined with a promoter sequence that will allow the gene to be expressed. This combination of genes is then introduced directly into the plant genome (Chrispeels and Sadava, 2003). To improve cassava by genetic engineering, an essential prerequisite as earlier stated, is the development of an efficient regeneration and transformation procedures.

**Cassava in vitro regeneration**

Plant cells are generally considered to be totipotent, thus being able to regenerate whole plants from single cells in vitro. The ability to regenerate in vitro is, however, often limited to certain tissues and developmental stages, and the requirements for transformation and regeneration competence may not always be compatible. Furthermore, a method for efficient transfer and stable integration of the transgenes into plant genomic DNA is essential for transformation, as well as a means for identifying and selecting transformed cells (Fregene and Puonti-Kaerlas, 2002).

The main constraint is usually not the delivery of foreign DNA to the regenerable cells, but the recovery of the transformed cells. Finally, the introduced genes must be correctly expressed in the primary transgenic plants and transmitted stably to their progenies (Zhang, 2000). As cassava is vegetatively propagated, the transgenes can be fixed already at the level of primary transgenic plants, and stable inheritance is of concern only when the transgenic plants are to be incorporated in breeding programs.

Plant regeneration through tissue culture can be accomplished using one of the three methods, namely, meristem culture, somatic embryogenesis and organogenesis. Figure 1 illustrates how all three methods are used in regeneration and recovery of transgenic cassava plants. Of the different explants used for regeneration, meristems are the tissue of choice as they represent ‘growth centres’ of plants (Fregene and Puonti-Kaerlas, 2002; Zhang et al., 2001). Therefore, this system is easy, fast and relatively genotype-independent. Applications of this system include germplasm preservation, micropropagation, transformation and eliminating virus and other pathogens from plant materials. In cassava, meristems can be induced to form multiple shoots on cytokinin-containing medium. Most of the shoots are derived from pre-existing auxiliary meristems, but also de novo formation of new meristems and shoots occurs (Konan et al., 1997). Transient and stable expression of both GUS and luciferase have been demonstrated in meristems and meristem-derived somatic embryos and multiple shoot clusters after particle bombardment (Puonti-Kaerlas et al., 1997).

Somatic embryogenesis is the production of embryo-like structures from somatic cells. The somatic embryo is a bipolar structure which is independent and not vascularity attached to the tissue of origin. This system is now the most commonly used regeneration method in cassava. In cassava, somatic embryogenesis is restricted to meristematic and embryonic tissues. Somatic embryogenesis can only be induced on a limited number of explants such as cotyledons of zygotic embryos.
Figure 1. Schematic representation of different regeneration steps in cassava (adapted from Zhang 2000).

Cassava has proven to be recalcitrant to plant regeneration from protoplasts. Cassava protoplast isolation and culture have been performed by various laboratories (Szabados et al., 1987), but regeneration was observed only in one instance and has not been repeated. Recently, protoplasts isolated from FECs and embryogenic suspensions of cassava cv. TMS60444 were found to divide and develop readily into callus after culture in a medium supplemented with 0.5 mg/l NAA and 1 mg/l zeatin (Sofiari et al., 1998). After 2 months of culture, about 60% of the callus had a friable embryogenic nature. One disadvantage of this system is the long span (≥20 weeks) from explant to suspension culture and to regenerated plantlets, which may result in somaclonal variation and loss of regeneration capacity, the most common problem associated with suspension cultures. Another limiting factor is the production of FEC, which is strongly genotype-dependent (Zhang, 2000).

A method for regeneration of cassava plants through somatic embryogenesis has been available since 1982 (Stamp and Henshaw, 1982). However, the use of embryogenic structures generated by this culture system as target tissues for genetic transformation via Agrobacterium (Calderón, 1988; Schöpke et al., 1997) and electroporation (Luong et al., 1995) has yielded at best only chimeric embryos. Taylor et al. (1996) developed an alternative regeneration system in which clusters of embryogenic cells are suspended in liquid medium. These suspension cells are far more suitable for genetic transformation protocols with regard to accessibility or regenerable cells and selection procedures. The first reports on successful regeneration of transgenic cassava plants have been published only in the second half of the 1990s (Li et al., 1996; Raemakers et al., 1996). The current status of cassava transformation is summarized in Table 1.

Cassava genetic transformation

Plant transformation is performed using a wide range of tools such as Agrobacterium Ti plasmid vectors, microprojectile bombardment, microinjection, chemical (PEG) treatment of protoplasts and electroporation of...
### Table 1. A summary of methods used in genetic engineering cassava programs.

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<td>Particle bombardment</td>
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Adapted from Fregene and Puonti-Kaerlas (2002).
protoplasts. Of the above-mentioned methods for delivering foreign DNA into plant cells, the most used are Agrobacterium-mediated gene transfer and particle bombardment (Fregene and Puonti-Kaerlas, 2002). Pathogenicity of different Agrobacterium strains is highly variable and genotype dependent (Chavariaga-Aquirre et al., 1993; Sarria et al., 1993).

The naturally evolved unique ability of Agrobacterium tumefaciens to precisely transfer defined DNA sequences to plant cells has been very effectively utilized in the design of a range of Ti plasmid-based vectors. Agrobacterium-based DNA transfer system offers many unique advantages in plant transformation including:

The simplicity of Agrobacterium gene transfer makes it a relatively inexpensive vector. A precise transfer and integration of DNA sequences with defined ends.
A linked transfer of genes of interest with the transformation marker.
The higher frequency of stable transformation with many single copy insertions.
Reasonably low incidence of transgene silencing and lastly.
The ability to transfer large T-DNA (>150 kb).

Cotyledons from somatic embryos of cassava cv. MCol22 have been the target for Agrobacterium-mediated transformation of cassava (Li et al., 1996). Their study showed that regeneration of transgenic shoots was achieved via organogenesis from somatic embryo cotyledon explants after co-cultivation with A. tumefaciens and selection on hygromycin or gentamicin. Agrobacterium strains LBA4404 (pTOK233) and LBA4404 (pBin9GusInt) gave the highest transient transformation rates. Schöpke et al. (1993a) reported the use of plasmids for transformation that contained an uidA-intron gene controlled by different versions of the Cauliflower mosaic virus (CaMV) 35S promoter and the htp or nptII genes as selectable markers. Optimal transient expression of uidA was observed when cotyledon pieces were co-cultivated for 4 days with Agrobacterium strain LBA4404. In another study by González et al. (1998), Agrobacterium-mediated transformation was applied to introduce the uidA-intron and nptII genes into cassava tissue derived from embryogenic suspension cultures.

Although the success of Agrobacterium vectors has been paramount, the technique continues to have problems and limitations. Resultantly, its inability to infect monocots inspired researchers to develop an alternative delivery system. Particle bombardment is a procedure in which microscopic gold or tungsten particles coated with genetically engineered DNA are explosively accelerated into plant cells. This technique has become the second most widely used vehicle for plant genetic transformation after Agrobacterium-mediated transformation system (Gray and Finer, 1993). Several distinct particle guns have been used including the Biolistic PDS 1000/He (Kirkert, 1993), which is the only commercially available device. The most attractive of the non-commercial devices is the particle inflow gun (Finer et al., 1992), which is based on a flowing helium device described by Takeuchi et al. (1992), since it can be fabricated from a steel plate with readily available parts and offers performance on par with the Biolistic PDS 1000/He (Brown et al., 1994).

The use of different marker genes is necessary for identification as stable transformation frequencies are low. The most commonly used visual markers are GUS-encoded by the uidA gene (Jefferson, 1987), the luciferase genes from the firefly Phonitis pyralis (Ow et al., 1986), soft coral Renilla reniformis (Mayerhofer et al., 1995) and green fluorescent protein (Chalfie et al., 1994). The most selectable marker genes encode for resistance to aminoglycoside antibiotics (Fraley et al., 1983), hygromycin (van den Elzen, 1985) and phosphinotrin (Wohlhenben et al., 1988).

The effectiveness of microprojectile-mediated system was shortly demonstrated successfully by scientists after the discovery in transforming monocots, the first of which was Black Mexican Sweet corn (Fromm et al., 1990). Raemakers et al. (1996) investigated the effect of different bombardment and culture parameters on transient and stable expression of the firefly luciferase gene (luc) after particle bombardment of cassava embryogenic suspension cultures. Continuous selection and subculture of light-emitting tissue eventually resulted in cultures consisting totally of transformed tissue. Differentiation and maturation of somatic embryos occurred on an MS-based medium supplemented with a complex mixture of organic components in addition to 4.14 µM picloram and 0.43 µM adenine sulfate. Different promoters (35S, e35S, 4Oe35S, UBQ1) fused to the uidA gene were bombarded into cassava leaves of cv. Señorita with a pneumatic particle gun (Schöpke et al., 1994b) in order to study their efficiency in cassava tissue. Transient gene expression was measured 24 h after bombardment with fluorometric GUS assay using methylumbelliferyl glucuronide (MUG) as a substrate. Higher activities measured with MUG assays corresponded to larger diameters of blue spots. Puonti-Kaerlas et al. (1997) used a particle inflow gun to investigate the efficiency of shoot meristem transformation in cassava. After bombardment with a particle preparation containing a range of sizes, particles
were found to have lodged in the first and second cell layers and even deeper. Using the uidA gene resulted in 50% of bombarded meristems showing 2-8 blue spots per meristem after GUS assays. Bombardment with the luc gene allowed screening for gene expression in living tissues and thus eliminating non-expressing plants. In a different study, Schöpke et al. (1997b) established and optimized conditions for particle bombardment of tissue derived from embryogenic suspension cultures of cassava cv. TMS60444. The optimal conditions for particle bombardment parameters were found to be 1100 psi pressure, 1.0 µm particle size, 2 bombardments/sample, and an osmotic treatment with 0.1 M sorbitol and 0.1 M mannitol. Observing these conditions resulted in an average number of 1350 blue spots/cm² of bombarded sample of embryogenic-derived tissue.

Positive selection is a new concept for the selection of transgenic plant cells (Joersbo et al., 1998). The transgenic cells are selected by the addition of a compound e.g. mannose, which is converted by the transformed cells into a compound inducing a positive response, for example, growth or shoot formation. Non-transgenic cells stay alive without shoot formation, which means that neighbouring cells are not exposed to toxic selections from dying cells. Simultaneously, cells containing the transgene can utilize a component in the medium which results in growth or differentiation and non-transformed cells remain unaffected, therefore having no detrimental effect in transgenic cells (Zhang, 2000).

Calderón (1988) was the first to describe transformed callus lines of cassava. He infected cassava leaf and stem pieces, and embryogenic callus with Agrobacterium containing plasmids with the coding sequences for neomycin phosphotransferase II (npt II), phosphinothricin acetyltransferase (bar), or β-glucuronidase (uidA). Southern blot analysis with one callus line demonstrated the stable integration of T-DNA into the cassava genome.

**Mechanisms of genetic engineering for virus resistance**

Plant virus diseases are major constraints in the cultivation of a wide range of economically important crops worldwide. The application of genetic transformation for increased resistance to the major cassava viruses is a major priority. Strategies for the management of viral diseases normally include control of vector population using insecticides, use of virus-free propagating material, appropriate cultural practices and use of resistant cultivars. However, each of the above methods has its own drawback. Sanford and Johnson (1985), working with bacteriophages described the concept of pathogen-derived resistance (PDR), which was later demonstrated by Abel et al. (1986). PDR resistance strategies have proved effective in other crops (Beachy, 1997) and are being developed against both the major viral diseases of cassava, namely, cassava common mosaic disease (CsCMD) and African cassava mosaic disease (CMD). Beachy’s illustration was in tobacco, by introduction of the coat protein (CP) of tobacco mosaic virus (TMV) into tobacco and observed TMV resistance in the transgenic plants. Many viral host resistance genes have now been isolated and are used in transgenic plants to provide protection against viral infection. In a number of crops, transgenics resistant to an infective virus have been developed by introducing a sequence of the viral genome in the target crop by genetic transformation (Dasgupta et al., 2003). These different crops include maize, ice, wheat, apricot, grape, papaya, pepper, tomato, sugar-beet and peanut to mention, but a few. Virus-resistant transgenics have been developed in many crops by introducing either viral coat protein (CP) or replicase (Rep) gene encoding sequences. Resistance obtained by using CP is conventionally called coat protein mediated resistance (CPMR). In this case, resistance has been shown to be due to an inherent plant response, known as post-transcriptional gene silencing (PTGS). It has been reported that gene silencing can be induced by plant virus infections in the absence of any known homology of the viral genome to host genes and this silencing may occur at the transcriptional or post-transcriptional level (Covey et al., 1997). Therefore it seems possible that plants can naturally escape virus infection in a post-transcriptional manner. Because of the essential nature of the viral movement protein (MP) for intercellular movement of plant viruses, movement protein sequence has also been used for achieving viral resistance (Okeese and Pinto, 2003). Other pathogen-derived approaches include the use of satellite RNA and defective-interfering viral genomic components.

Fauquet et al. (1993) employed Agrobacterium-mediated transformation of N. benthamiana, which can be infected by both ACMV and CsCMV to study the expression of the viral CPs and their ability to provide protection against the respective viruses. Plants transgenic for the ACMV-CP gene were shown to contain low levels of mRNA corresponding to the coding sequence of the ACMV-CP gene. When the CP-positive plants with ACMV resulted in some degree of resistance at a virus concentration of 20-100 ng/ml.

The application of plant viral replicase-associated genes for the transformation of host plants, which leads to the generation of plant lines resistant to the donor virus, is termed replicase-mediated resistance. It has been shown to be effective in several cases (Palukaitis and Zaitlin, 1997). Hong and Stanley (1996) found that integration and expression of the ACMV AC1 (Rep) gene driven by the enhanced 35S promoter in N. benthamiana, imparted elevated resistance to infection by this virus. Sangaré et al. (1999) showed expression of mutated AC1 gene to delay symptom apparition and severity and
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Plant virus diseases, including CMD continue to cause severe constraints on the productivity of a wide range of economically important crops worldwide. The application of genetic transformation for increased resistance to cassava begomoviruses is a major priority. In SA, interest in cassava production has increased astronomically with Cassava Starch Manufacturing Company (CSM) taking the lead in Dendron, Limpopo Province and Barberton, Mpumalanga Province. CSM is a privately owned commercial company that belongs to Mr. Jim Casey. The company has dedicated more than 2000 ha of land to cassava production. In addition, CSM has contracted small-scale farmers to produce the crop for processing purposes. The main markets for the starch are food, textile, paper, corrugated cardboard and mining industries in SA. There are plans to extend cassava production in several districts in Mpumalanga and KwaZulu-Natal provinces, also using contracted small-scale rural farmers.

In SA, cassava transformation capability is still being developed amid a concern about declining cassava yields due to infection by begomoviruses. It is considered that cassava transformation technology can be transferred to the African environment when suitable institutes and individuals have been identified in the continent. One such laboratory, ILTAB has established a program by which African scientists are trained in cassava biotechnology and return to their home institutions to help transfer skills and capacity building. However, the issue of staff turnover due to lack of resources and proper funding can frustrate such a program. Currently, USAID through CIAT and ILTAB are funding a program that will enable Agricultural Research Council (ARC) scientists in SA train elsewhere in developed laboratories on cassava transformation aiming at improved starch qualities and resistance against CMD. South Africa could test for efficacy of transgenic cassava as issues concerning intellectual property rights (IPR) and biosafety implications are already legislated and in place. These issues can be a bottleneck in many African countries as recently experienced by ILTAB while trying to deploy a field test on their cassava replicase transgenic event. Successful application of transgenic technologies in cassava will depend not only on technical advances, but also on successful transfer of knowledge, tools and expertise to southern African countries wherein cassava has both important socioeconomic and industrial roles. In order for the cassava farmers to benefit from cassava biotechnology advances already achieved by well established overseas laboratories, e.g. ILTAB, Wageningen University, ETH, Ohio State University and CIAT, there has to be a strong technology transfer.
programme that will support local scientists in the transfer of already existing cassava transformation systems.

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