Status of Agricultural Biotechnology in South Africa and Developments in sub-Saharan Africa

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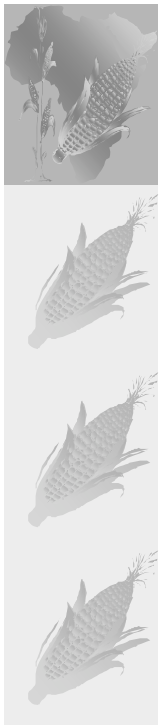
University of Cape Town
South Africa

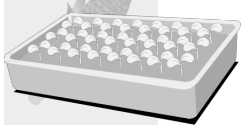


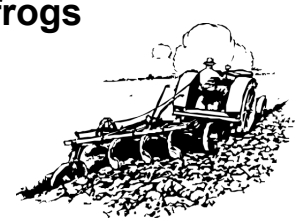
GM Crops in South Africa

- 1st in Africa; 8th in world
- Maize = 78% (White = 79%; Yellow = 77%)
- Soybean = 85%
- Cotton = 98%

Some results of insect resistant cotton in South Africa

- **Small scale farmer increased profits: 1997 - 4 participated; 1998 – 75; 1999 – 411; 2000 – 644; 2002 - >2000**
- **2006 – 2260; 2009 - 750**
- **Drop due to cotton gin problems**
- **↑ non-target insects, birds and frogs**
- **↓ insecticide poisonings**



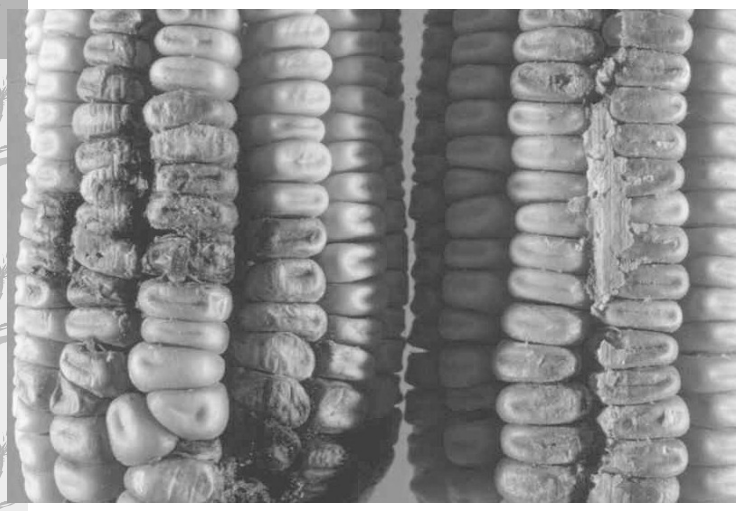


Agricultural biotechnology research in Southern Africa

- ✶ Virus resistance
- ✶ Herbicide resistance
- ✶ **Insect Resistance**
- ✶ **Fungus resistance**

MAIZE STORAGE CRIBS IN TRANSKEI

Insect sensitive maize



MOULDY MAIZE EARS INFECTED BY *FUSARIUM*

HUMAN DISEASES ASSOCIATED WITH MYCOTOXINS IN FOOD

- **Acute toxic hepatitis – Aflatoxin**
- **Liver cancer – Aflatoxin**
- **Oesophageal cancer – Fumonisin**
- **Neural tube defects - Fumonisin**

LIVER CANCER IN MOZAMBIQUE

HUMAN DISEASES ASSOCIATED WITH MYCOTOXINS IN FOOD

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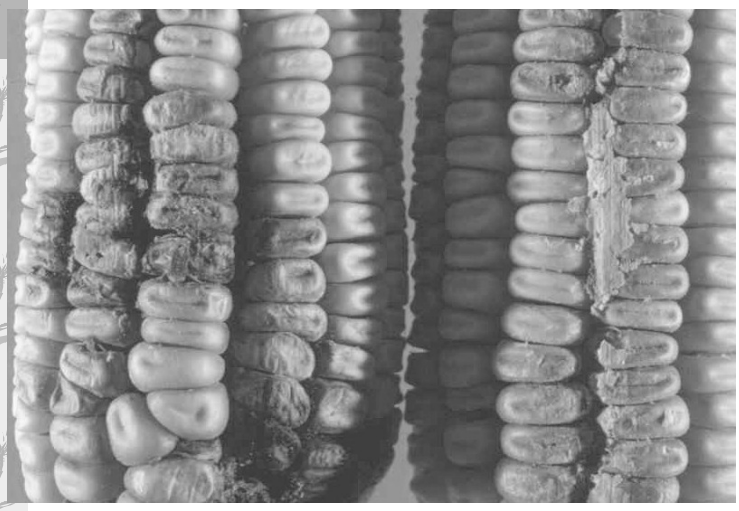
Insect sensitive maize



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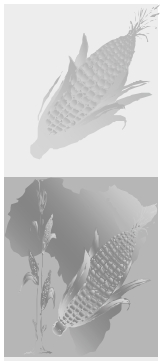


Mycotoxin levels in GM vs non-GM maize in France (*Science* 2010)

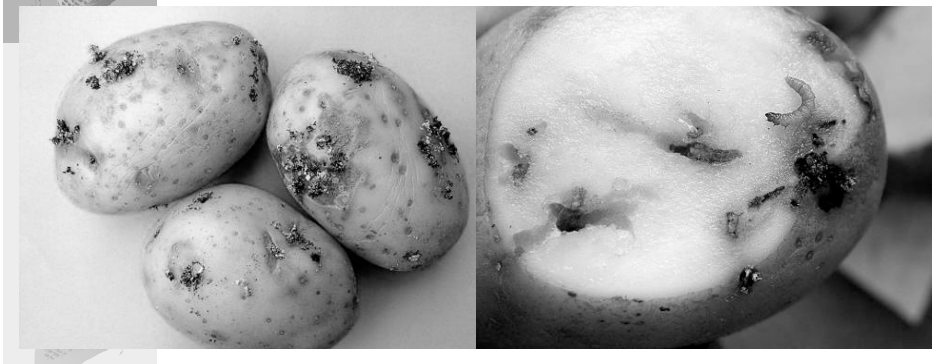
- **90% decrease in fumonisins (*Fusarium*)**
- **EU regulations on mycotoxin-containing maize →**
  - **93% of GM maize can be sold**
  - **45% non-GM maize can be sold**
- **BUT EU → no GM maize can be grown**

African Biofortified Sorghum

- **High lysine, increased Vitamin A, iron and zinc**
- **International consortium funded by Bill and Melinda Gates Foundation**
- **Glasshouse trials in South Africa**
  CSIR

Regulatory Decision: DENIED

- **No biosafety level III glasshouse**
  OOOPS → glasshouse already approved by Dept of Agric
- **MAY apply in future for field trials**
  ?????
- **Results: glasshouse trials in Kenya**
  Permission in 3 months
- **Decision reversed after TWO years**
  Too late!



Potato Tuber Moth Damage

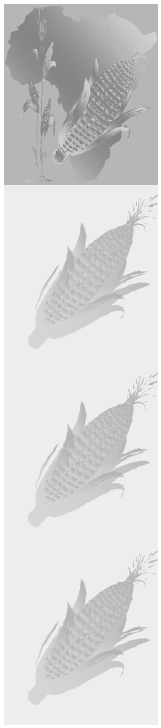
Potatoes resistant to tuber moth

Data supplied:

- Agronomic performance
- Molecular data
- Food and feed safety
- Environmental safety
- Socio-economic impact data
- Stewardship program/plan

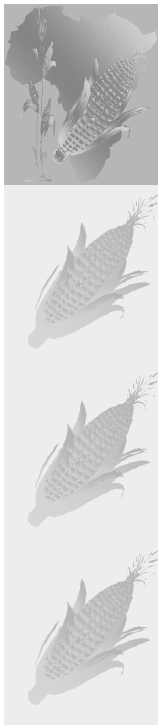
Regulatory decision: ***DENIED***

- September 2009
- No ability to address Exco concerns on technical issues (all could be addressed)
- Exco decided small-scale farmers do not need this technology; segregation?; risk management?; not a major pest of stored potatoes



Intervention: National Biotechnology Advisory Committee

- Role: Advise Minister S&T
- Advice: Problems with administration of GMO Act (Aug 2010)
- Promise: who on ExCo and scientific basis of decisions
- Article in AgBioForum based on ICABR, Ravello

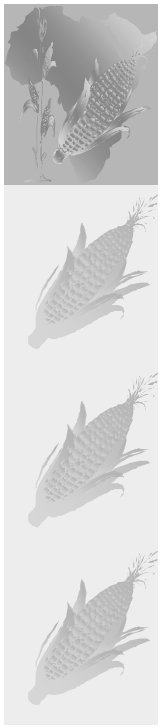


Consumer Protection Act

Any person who produces, supplies, imports or packages any goods must display..a notice..that discloses the presence of any genetically modified ingredients…

Regulations open for comment

Minister unaware → meet with Minister Trade and Industry → difficulties/impossibilities



Labelling Implications: Lessons from the Philippines

- Farmers: +12%
- Manufacturers: +11 – 12%
- Consumers: +12%
- Govt Implications: regulatory costs incl. monitoring and verification; testing facilities, training

AFRICAN AGRICULTURAL TECHNOLOGY FOUNDATION

FONDATION AFRICAINE POUR LES TECHNOLOGIES AGRICOLES

Agricultural biotechnology in sub-Saharan Africa

Insect resistant cowpea for West Africa

COWPEA (beans)-Naman talaka

Dr M F Ishiyaku

Cowpea & Maruca

Resistance due to Bt (TJ Higgins of CSIRO)

Biosafety Requirement

- Controlled Field Trials in Puerto Rico 2009
- CFT in Nigeria 2010

Agricultural biotechnology in sub-Saharan Africa

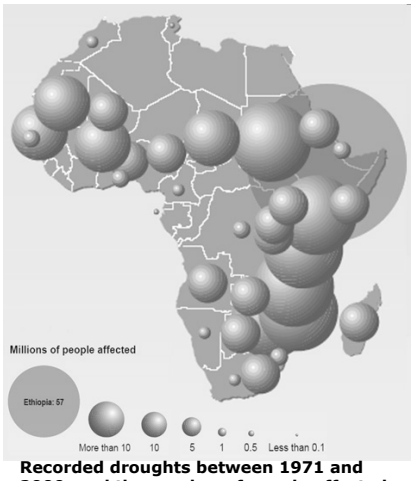
Water Efficient Maize for Africa
WEMA

Water-Efficient Maize for Africa (WEMA)

- A public-private partnership to develop and deploy royalty-free drought-tolerant maize varieties to SSA smallholder farmers
- As response to the devastating effects of drought
- Combining Breeding and Biotechnology

Rationale for WEMA

- **Africa drought-prone**
- **Maize is the most widely grown staple crop in Africa – affected by drought**
- **In 2003 WFP spent $0.57b on food emergency due to drought in Africa**
- **Risk of drought prevents investment in BMP**
- **Yield stability is key to unlock the value of basic inputs for Africa Green Revolution**



Recorded droughts between 1971 and 2000, and the number of people affected

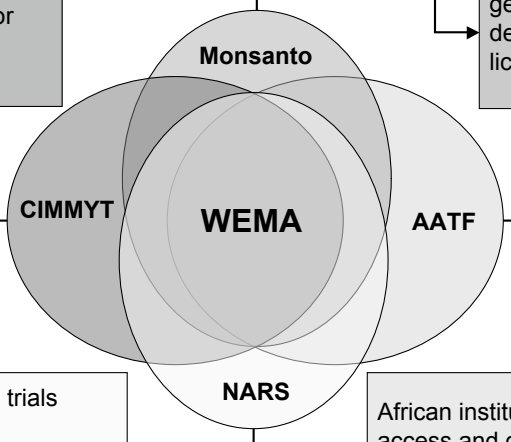
Drought Stress in Maize, Kenya

Source: James Gethi, 2009

WEMA Partnership

World leader for breeding maize for African agro-ecological zones

World leader in MAB, gene discovery, trait development and trait licensing

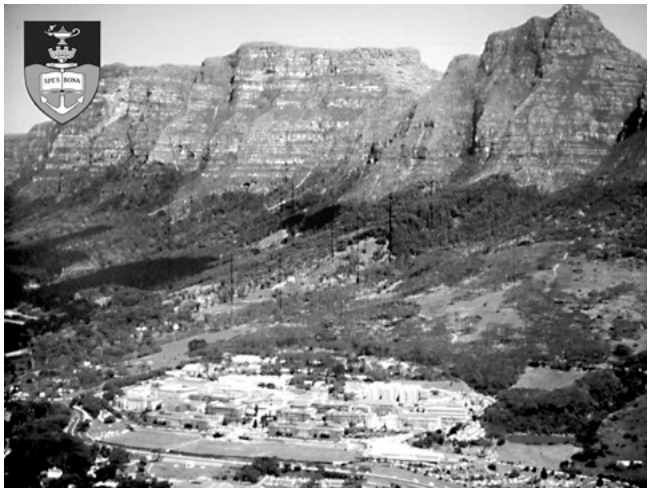


- Expertise in field trials
- Test DT maize
- Adapted checks
- Capacity building opportunities

African institution mandated to access and deliver proprietary technologies to smallholders African farmers

Progress

- Gene = *cspB* (cold stress protein from *Bacillus)*
- Confined field trial (CFT) sites developed in partner countries in locations with rain-free window for at least 3 months
- African adapted inbreds undergoing trait integration
- CFT trials in South Africa with Monsanto's lead commercial event (MON 87460)



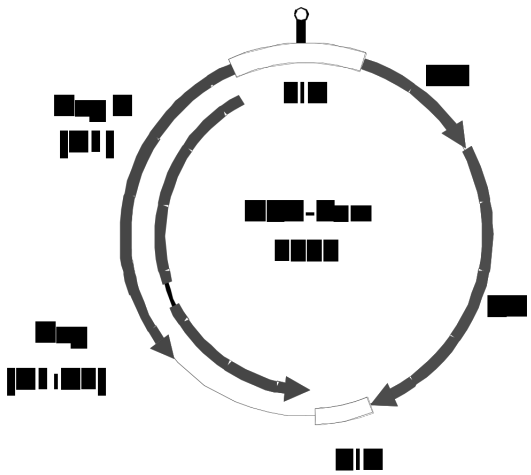
Agricultural biotechnology in sub-Saharan Africa

- Maize resistant to Maize streak virus (MSV)

Maize streak virus (MSV) is endemic in Africa causing huge economic losses to commercial

and small scale farmers

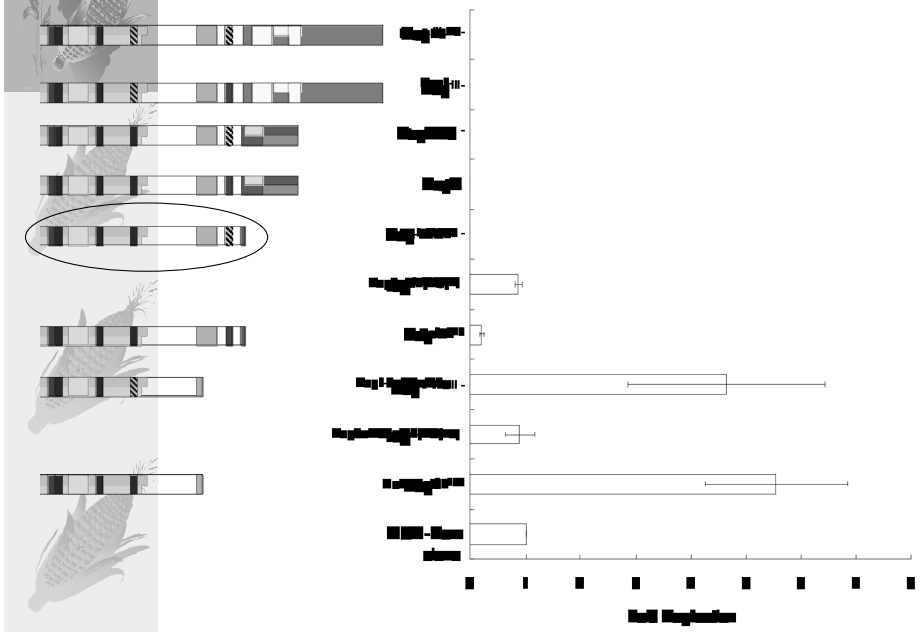
MSV genome

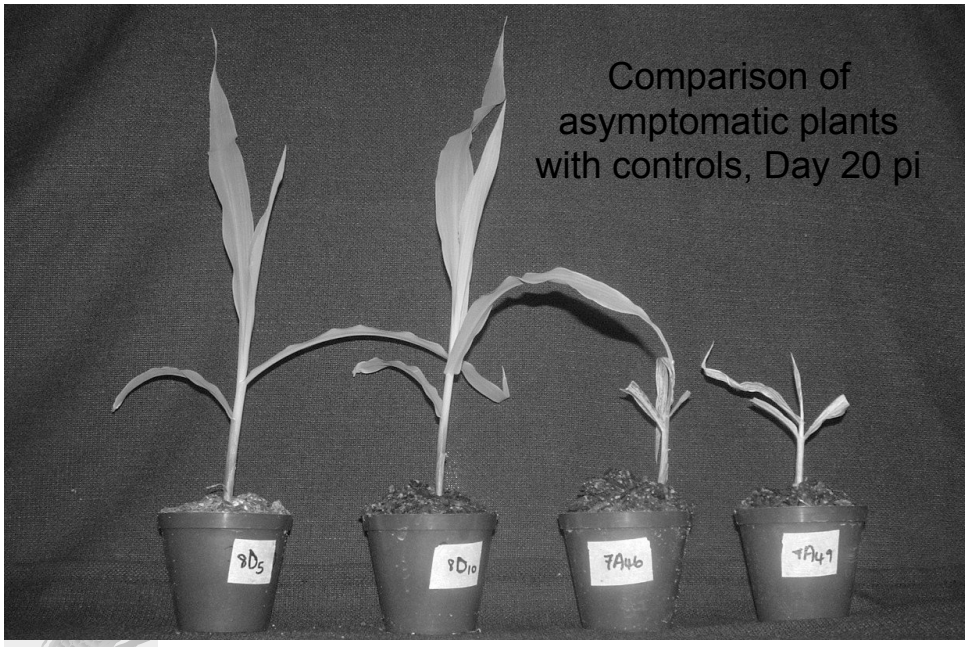


MSV
Resistance Strategy

- Most plant viruses = RNA → coat protein^{R}
- MSV = DNA virus: CP→ no protection
- Virus Replication Associated Protein → replication initiation as multimers
- Mutant, truncated Rep → inhibition virus replication

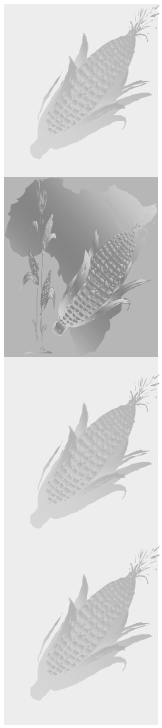
Effects of mutant Reps on viral replication





Transgenic

Non-transgenic



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Maize streak virus-resistant transgenic maize: a first for Africa

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Keywords: African biotechnology, geminivirus, maize streak virus, maize streak virus-resistant maize, maize yield improvement, pathogen-derived resistance, transgenic maize.

Summary

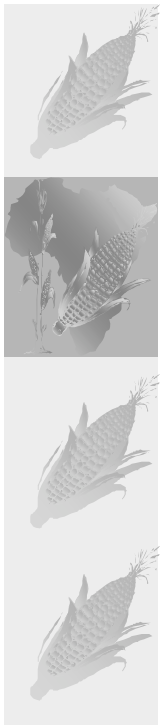
In this article, we report transgene-derived resistance in maize to the severe pathogen maize streak virus (MSV). The mutated MSV replication-associated protein gene that was used to transform maize showed stable expression to the fourth generation. Transgenic T_2 and T_3 plants displayed a significant delay in symptom development, a decrease in symptom severity and higher survival rates than non-transgenic plants after MSV challenge, as did a transgenic hybrid made by crossing T_3 H+II with the widely grown, commercial, highly MSV-susceptible, white maize genotype WM3. To the best of our knowledge, this is the first maize to be developed with transgenic MSV resistance and the first all-African-produced genetically modified crop plant.

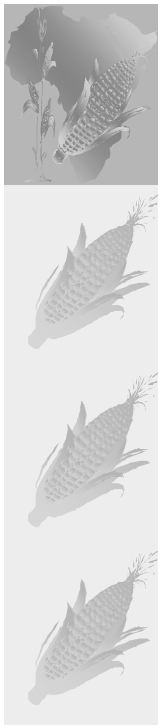
Introduction

Maize was first introduced to Africa by Portuguese traders in the 16th century, and has become the continent's staple food crop, making up more than 50% of total caloric intake in local diets (Sinha, 2007). However, average maize yields of 1.2 tonnes/ha are just a quarter of global averages (http://faostat.fao.org), a disparity exacerbated by the susceptibility of maize to pathogen attack. Maize streak disease (MSD), caused by the geminivirus maize streak virus (MSV), is the major viral pathogenic constraint on maize production in Africa (Wambugu, 1999; Bosque-Pérez, 2000), making resistance to MSV a key target for crop improvement.

Biotechnological solutions to Africa's food security problems (Mosan *et al.*, 2004) have been flagged as a vital component of the United Nation's Millennium Development Goals (Acharya *et al.*, 2003; Ayele *et al.*, 2006). Yield increases and economic benefits to both commercial and resource-poor farmers of *Bacillus thuringiensis* (Bt) toxin transgenic cotton and maize have been well documented in South Africa and other developing countries (Pray *et al.*, 2002; James, 2003; Qaim and Zilberman, 2003; Thirtle *et al.*, 2003; Toenniessen *et al.*, 2003; Gouse *et al.*, 2004; Morse *et al.*, 2004).

Starting with the first accounts of pathogen-derived resistance (PDR) over 20 years ago (Sanford and Johnson, 1985; Powell-Abel *et al.*, 1986), there have been numerous reports of genetically engineered virus resistance (mostly coat protein derived) in economically important food crops, including tomato (Nelson *et al.*, 1988; Sanders *et al.*, 1992; Kunik *et al.*, 1994; Noris *et al.*, 1996), papaya (Fitch *et al.*, 1992; Liu *et al.*, 1997) and potato (Kaniewski *et al.*, 1990; Kawchuk *et al.*, 1990; Lawson *et al.*, 1990; van der Wilk *et al.*, 1991). More recently, monocots have been engineered for virus resistance, including sugarcane (Ingelbrecht *et al.*, 1999), ryegrass (Xu *et al.*, 2001), barley (Wang *et al.*, 2000), rice (Hayakawa *et al.*, 1992; Pinto *et al.*, 1999), wheat (Swaminathan *et al.*, 2000, 2002) and maize (to maize dwarf mosaic potyvirus and maize chlorotic mottle machlomovirus; Murry *et al.*, 1993). Resistance to numerous geminiviruses has been achieved using a PDR approach (reviewed by Vanderschuren *et al.*, 2007); however, none of these reports involved resistance in a monocot species. We have recently demonstrated the first successful PDR strategy for MSV resistance in a model





AG BIOTECH

GM Technology Develops in the Developing World

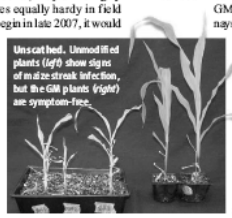
The first genetically modified crop developed entirely in Africa is gearing up for field trials. Its success would be a milestone

About 100 km north of Durban, South Africa, in a greenhouse chamber no larger than a walk-in closet, Frederik Kloppers clips a slender vial to a baby maize plant's new leaf. Inside the tube sits an insect with a potentially deadly bite, at least deadly to corn. This African leafhopper (*Cicadulina mbila*) carries maize streak virus, a scourge endemic to sub-Saharan Africa that devastates fields. Kloppers, a plant pathologist and technical manager at Pannar Seeds in Greytown, South Africa, gathers a dozen more tubes from the insect house and clips them to additional plants. Tomorrow, after the bugs have eaten their fill, he'll remove the tubes and then wait.

The fruit of more than a dozen years of effort, these maize plants have been genetically altered to resist infection by the virus. In greenhouse studies so far, the plant is highly resistant. If it proves equally hardy in field trials scheduled to begin in late 2007, it would be a milestone: the first-ever genetically modified (GM) crop developed by Africans for Africa.

But Kloppers and the plant's inventors, microbiologist Jennifer Thomson, virologist Edward Rybicki, and colleagues at the University of Cape Town (UCT), have much larger goals in mind. In a region where chronic hunger is the norm, GM maize could help alleviate grain shortages and potentially even boost economic development, says Thomson. And because plans call for selling the seed to small-scale and subsistence farmers for minimal profit, the inventors also hope it will help burnish the dim reputation of GM technology.

None of that is assured, Thomson and Rybicki concede. The plant could still fail in the field, as other African GM crop varieties such as sweet potato and cassava have done. The failures not only have disappointed the technology's advocates, but they've also fanned the flames of anti-GM sentiment. Although South Africa is one of the few African countries to permit farmers to plant GM crops within its borders, naysayers there, who still have substantial clout, have condemned the technology as a mere moneymaking tool for Western companies. Moreover, they remain unconvinced that home-grown efforts such as UCT's maize will succeed. Another failure would give anti-GM groups even more ammunition. The



Unscathed. Unmodified plants (*left*) show signs of maize streak infection, but the GM plants (*right*) are symptom-free.

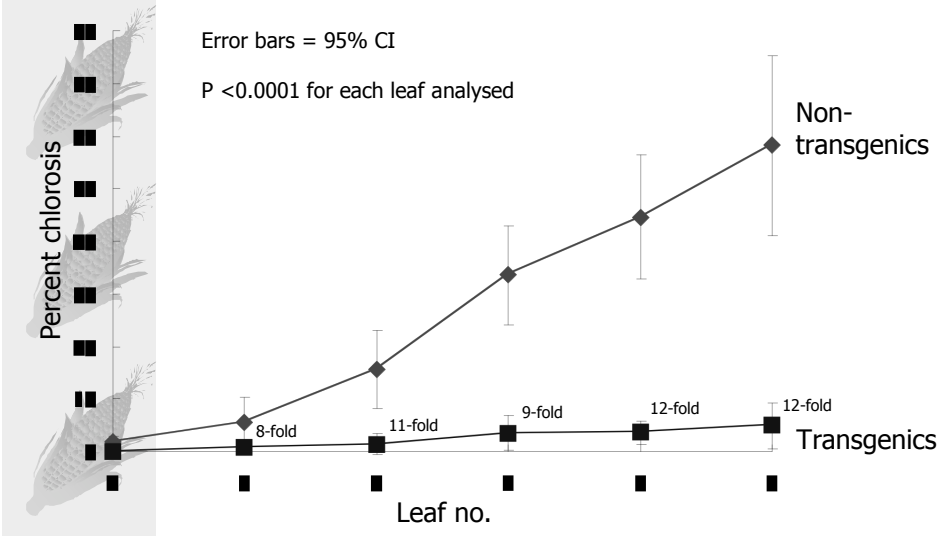
CREDIT: DONNE SHEPHERD/UNIVERSITY OF CAPE TOWN

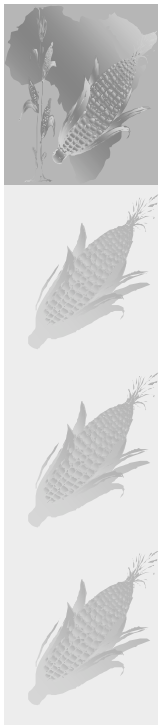
WM3 non-transgenics

Transgenics

Immunity

Average Percent Chlorosis
WM3 elite maize transgenics vs non-transgenics





Biosafety Regulations

- No African developed transgenic crops tested for biosafety approval to date
- Will be unable to commercialise any such crops without this approval
- Field trials = $$$
- What about SA regulatory hurdles?

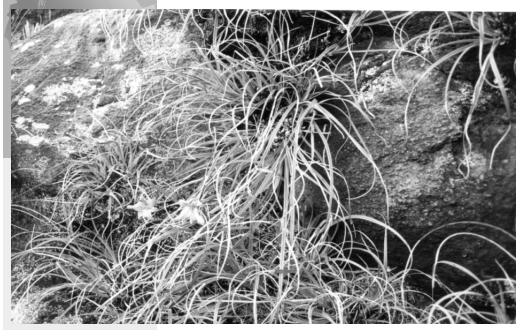
Agricultural biotechnology in sub-Saharan Africa

- **Drought tolerance**

We have taken genes from a resurrection plant for introduction into crops to generate drought tolerant crops

Hydrated

Dehydrated



Genes being used

Xv SAP1 → **Stress associated protein**
No similar genes recorded
Codes for membrane, signalling protein

Xv Ald1 → **Aldose reductase converts glucose to sorbitol, an osmoprotectant**

Xv Prx2 → **Peroxiredoxin ie an antioxidant involved in dehydration stress response**

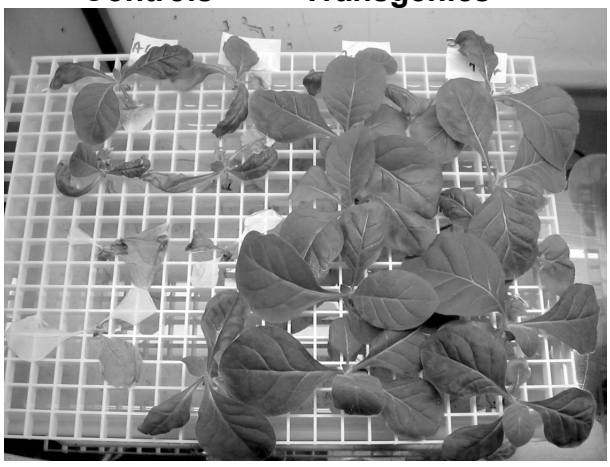
Xv G6 → **Dehydration stress response protein**

+ Stress Inducible Promoter

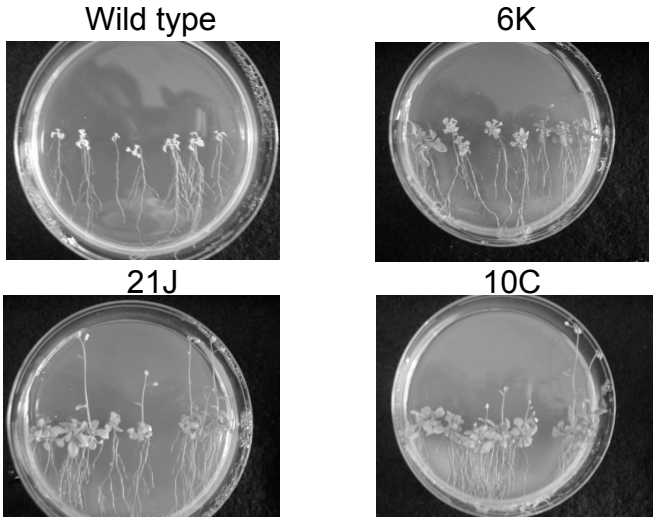
Xv SAP1 → **dehydration^{R} in tobacco**

- Water

Controls **Transgenics**

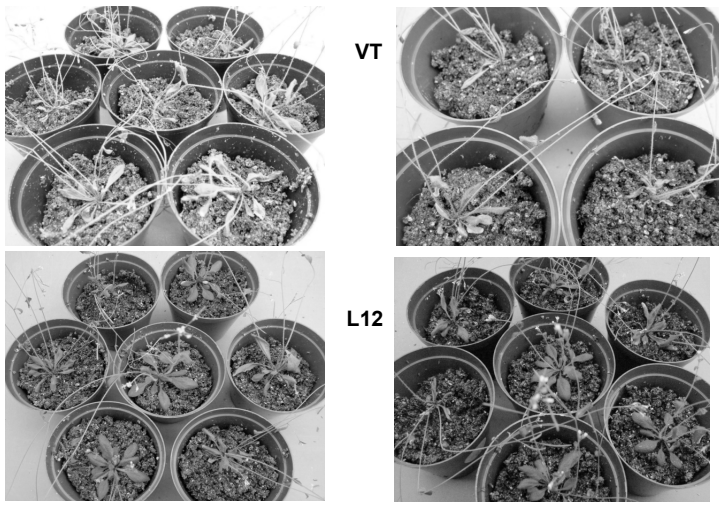


Xv SAP1 → heat^{R} in Arabidopsis



Heat treatment

Xv Ald1 → dehydration^{R} in Arabidopsis



Dehydrated transgenic Arabidopsis plants (bottom) Control (top) expressing aldose reductase

Maize Transformation

Prof Jesse Machuka + Team

Kenyatta University

- ✶Agrobacterium transformation
- ✶Biosafety compliant glasshouse
- ✶On equator → 2 crops/year
- ✶Confined field trials at KARI

GM Crops in Africa

Egypt	1st country after SA to plant GM maize commercially
Burkino Faso	Planting GM cotton
Uganda	"Biotechnology is one of the frontiers of agricultural research today" Fred Omach, Minister of Finance
Kenya	President Kibaki signed biotechnology approval bill in 2009. Cotton and maize trials underway.

GM Crops in Africa (cont.)

Malawi	Biotechnology bill approved 2008 “My government recognizes the pivotal role biotechnology can play towards economic growth and poverty reduction.” President Wa Mutharika
Nigeria	“The potency of GM crop technology for increased productivity, nutrition and crop resistance to pests and drought is no longer questionable.” Mrs Grace Ekpiwhere, Minister of Science and Technology.

Agricultural biotechnology in sub-Saharan Africa

- **Nutritionally enhanced sorghum**
- **Insect resistant potato**
- **Drought tolerant maize**
- **MSV resistant maize**