Sustainable biotechnology for sub-Saharan Africa: can it be implemented and maintained?

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The industrialised world's plant biotechnology portfolio is based on a limited number of large commodity crops and input traits, and in general is unavailable and unaffordable, if not unsuitable, to the needs of sub-Saharan Africa (SSA) where per capita agricultural production has decreased since the 1960s. Governments and organisations involved in providing technological help must take into account the conditions under which small-scale — often subsistence — farmers of a particular region work. It is suggested that in order to be sustainable, biotechnology for SSA should in the first instance be tissue culture-, molecular marker- and biocontrol-based, as well as strongly orientated toward regional crop diversity. However, many of the constraints that retard development in SSA, for example, poverty, chronic malnutrition, urbanisation and HIV/AIDS, will also initially affect the implementation and maintenance of viable biotechnology programmes.

Introduction

Agriculture forms the economic backbone of most of the countries in sub-Saharan Africa (SSA), where up to 90% of the population lives in the rural section (Blackie 2002) but where urbanisation is a more recent, rapid and massive phenomenon connected to insufficient agricultural growth (Griffon 2002). Agriculture in SSA is dominated by a subsistence sector that is subject to many constraints, including increasing degradation of land and water resources, unpredictable climatic conditions, low capital input, and use of low-yielding, unimproved technologies (Mukiibi 2002). In reality, the list of constraints is almost endless and can be extended to: lack of property rights, the impact of malaria, measles, tuberculosis and especially HIV/AIDS, on the agricultural workforce, as well as unfavourable economic policies adopted by industrialised countries that disallow African farmers to compete successfully overseas, and lack of appropriate local government support. A major constraining factor is that one-half of the population engaged in subsistence agriculture is impoverished.

The FAO (Food and Agricultural Organisation) estimates that nearly 200 million people in SSA are chronically undernourished. Between now and 2025 the urban population is expected to increase by 160% (UNCHS, cited in Pinstrup-Andersen 2002), accompanied by an induced shift of poverty, food insecurity and child malnutrition to urban areas. Pinstrup-Andersen (2002) argues for challenges that will provide an empirically sound basis for policy and programmes to secure an efficient future food supply. At present, the majority of the people are still rural and there is typically a direct link between agricultural production and food security. For the present, Pinstrup-Andersen (2002) regards the industrialised world's biotechnology portfolio as either largely unavailable or unaffordable to sub-Saharan Africa; while Blackie (2002) regards much of it as unsuitable.

Poverty should be able to be alleviated through improved technologies, but only when the latter are available and appropriate. Many are of the opinion that strategic research and high quality science are incompatible with the complex demands of the agenda required by Africa for agricultural development and food sufficiency. Yet, technologies that improve people's lives do not necessarily have to be of the hi-tech or hi-biotech variety. There is scope for making more effective use of simple biotechnological solutions, especially where these can be shown to support agricultural development and the sustainable use of natural resources. This is not to say that hi-biotech research and development of competence should be neglected, but as Blackie (2002) points out ‘if technology cannot be translated into practical use then
it probably is not good enough for the problem at hand’. In Africa, in the face of a number of chronic problems it is practical use that dictates.

Constraints

As many, if not all, of the constraints mentioned above would also militate against the application of viable biotechnological programmes in efforts to establish food security and provide a minimum survival income, two of the questions that can be posed in relation to the kind of biotechnology required in SSA are: (1) should it be a commodity-driven biotechnology involving a limited number of crops, as practised in the industrialised world or (2) given the enormous crop diversity of SSA, one that is targeted toward regions? To answer these two questions a number of the constraints are considered here in more depth.

Southern Africa

Sub-Saharan Africa comprises roughly four regions: western, eastern, central and southern. At any particular time adverse conditions experienced in one region may not be common to the other regions. Sackett (2003), special UN envoy for Humanitarian Needs in Southern Africa, has given an account of the food crisis that is currently (2003/2004) affecting more than 15 million people in central and southern Africa, specifically in Lesotho, Swaziland, Mocambique, Malawi, Zimbabwe and the Democratic Republic of the Congo, all countries that have been exposed to severe drought in 2002/2003. The author emphasises that this ‘food crisis is about so much more than food and it isn’t going away’. Not only is lack of rain responsible for crop failure (in Mocambique in 2000/2001 it was severe flooding), but extreme poverty, economic decline, chronic malnutrition, questionable government policies, and limited access to vital agricultural inputs have contributed. However, the major exacerbating factor is HIV/AIDS, which lies at the heart of the humanitarian crisis, killing millions of the most productive people — including a disproportionate number of women — prematurely, and leaving millions more too sick, too poor and overburdened to provide for themselves and their families. By 2020, HIV/AIDS will have claimed 20% of South Africa’s agricultural workforce.

Rapid urbanisation

In comparison with 1975, it is predicted that by 2015 urbanisation in South Africa would have increased (in per cent) from 48 to 67, in Kenya from 13 to 47, in Nigeria from 23 to 56 and in Zimbabwe from 20 to 46. According to Vidal (2003) a recent study by the UN Human Settlements Programme (UN-Habitat) reported that urban slums were growing so fast that the balance of global poverty was shifting from the countryside to the cities (see also Pinstrup-Andersen 2002). Africa has 20% of the world’s slum dwellers. The Kibera district outside Nairobi, Kenya, is home to an estimated 700 000 people, while the Ashaiman slum in Ghana is larger than the city of Tema, which it surrounds. The study’s authors found that the world’s urban population increased by 36% during the 1990’s and it is expected to double to about 4 billion over the next 30 years. They concluded that: ‘Slums are the product of failed policies, bad governance, corruption and a lack of political will. Very few countries have recognised this critical situation and very little effort is going into providing jobs or services’. Seen against this background one might be excused for lack of exuberance at the prospect of an immediate biotechnological revolution in Africa.

Griffon (2002) described the urban hinterland as characterised by productivity rings. The ring closest to the city provides perishable products such as vegetables, fruit and dairy produce, while more distant rings produce less perishable ones such as grains and pulses, and semi-intensive products like open-field vegetables, poultry and livestock emanating from the area in between. This pattern will be familiar to those living in Africa, as will the results of unplanned urban expansion through informal housing and slum development, namely increased water, soil and air pollution around the major cities. The end result is a disturbance of the dynamics of sustainable development offered by such productivity rings (Griffon 2002).

Smallholder agriculture

Blackie (2002) argued that vigorous and productive smallholder agriculture is central to the welfare of the peoples of the African continent, but something which appears not to be central to the vision of most African countries. This author points out that large-scale agriculture is too capital intensive and generates far too little employment to meet current and future needs. The ability of African smallholders to respond to the challenge of new circumstances has been severely hindered by factors outside their influence. Blackie mentions three hypotheses to underscore his conviction that a new approach is needed: (1) The fundamental productivity issues facing most African farmers, who are smallholders, are often those for which agricultural experts have few realistic answers. In other words, much of what is promoted as improved technology is of poor quality. (2) The capacity of indigenous talent to drive change in Africa is consistently underestimated and undervalued. (3) The scale of the problem is such that the continent will require long-term scientific and technical support.

Some countries, e.g. Zambia and Zimbabwe, where large-scale intensive and extensive agriculture once provided food sufficiency, are now net recipients of food aid. The tendency in these countries, and probably eventually also in South Africa, is toward small-holding, small-plot and, in the worst-case scenario, subsistence agriculture.

Welfare and subsistence farmers

The reluctance of the European Union (EU), the USA and Japan and their welfare farmers to dismantle their market-distorting agricultural policies (International Herald Tribune 2003) betrays an unwillingness to make the sacrifices that poorer nations have been asking them to put into effect. Recently, grudging steps were taken by the EU toward reforming its Common Agricultural Policy (CAP) that is partly responsible for driving down commodity prices and in helping to confine many farmers in the Third World to subsistence. The EU, in spite of lofty aims concerning biotech-
nology in developing countries (Consultation Document 2001), places 140% tariffs on many imports from Africa. In respect of sugar alone, it supports its own sugar beet farmers to the extent of USD 1.6 billion a year, then dumps surpluses on overseas markets. China and the USA, with 25% and 21% of the world market in cotton, respectively, both subsidise cotton production. West and Central Africa's share of the world cotton market is only 5%, but some 10 million people make their living from a crop they can produce at costs 50% less than American cotton.

**Sustainable development**

The United Nations-sponsored World Summit on Sustainable Development in Johannesburg in September 2002 yielded few specific commitments but did generate a promise to cut by half by 2015 the number of people with inadequate water and sanitation. There is evidence that if unglamorous sewerage and hygiene projects can be made sustainable they will help a billion people and do much to alleviate diarrhoea and cholera and other water-borne diseases that strike the poor disproportionately. Could not the same principle using new but less glamorous biotechnology help to thwart hunger? The green revolution that transformed much of the agriculture in India and China has largely bypassed the African continent (The Economist 2001a), where the only answer to food security appears to lie in improving the productivity of its poor farmers. In this regard, the answer does not only lie in genetic modification (GM) of crops.

One of the problems in Africa is that indigenous crops such as leafy vegetables and roots (Allemann et al. 2004, Janse van Rensburg et al. 2004) that sustain small-scale farmers and their families, being diverse, low-volume crops, do not feature on the priority list of agriculture biotechnology companies who carry out genetic manipulation for profit. These companies have little incentive to cater for customers who cannot buy their products and services (Bie 2002) and occasionally also display little understanding of the important roles that small-plot and subsistence agriculture play on the African continent. The hope for sustainable agriculture in Africa will have to include more emphasis on less glamorous but nevertheless essential, feasible and less cost-intensive aspects of plant biotechnology, addressing areas of training, capacity building and job creation, while at the same time taking account of traditional knowledge (Modi 2004). If international agribusiness companies are genuinely interested in contributing to Africa's food security, they will be forced to consider the freeing of relevant enabling technologies from patent restrictions, and diversifying their efforts away from maize in favour of indigenous crops. Cereal yields in SSA — at about one t ha⁻¹ — have increased very little since the 1960s and maize yields are only 44% of the mean yield for all developing countries, down from nearly 70% forty years ago (Pinstrup-Andersen 2002).

**Agricultural Research in Sub-Saharan Africa**

Funds for agricultural research by African countries are limited and, in some countries, decreasing. The funds comprise only about 0.5% of the agricultural GDP, compared to 2.5% in industrialised countries. The private research industry, strongest in South Africa but controlled by transnational agribusiness parents, cannot (and even if it could, probably would not) cater for poor farmers due to the latter's lack of purchasing power over goods, technologies and services (Bie 2002). Yet, agriculture remains the mainstay of the SSA countries.

Agricultural research in SSA can be viewed at three levels: national, regional and international (Mrema 2002). At the national level, research consists of two types of organisation: National Agricultural Research Systems (NARS) and university departments of biology and agriculture. Non-Governmental Organisations (NGOs) and the private sector are involved in the development of agriculture to a much lesser degree. Generally, the NARS have been judged to have performed poorly and scepticism exists about the effectiveness and efficiency of NGOs (White and Eicher 1999, Mrema 2002, Theroux 2002).

At the regional and international levels, a plethora of organisations and programmes promote research, information exchange and technology transfer. They include ISNAR (International Service for National Agricultural Research), SPAAR (Special Program for African Agricultural Research) and ISAAA (International Service for the Acquisition of Agri-biotech Applications), ARF (Agricultural Research Fund administered by the World Bank) and USAID (United States Agency for International Development). There are three Sub-Regional Organisations (SROs): SACCAR (Southern African Centre for Cooperation in Agricultural and Natural Resources Research and Training), CORAF (Conseil Ouest et Centre Africain pour la Recherche et le Developpement Agricoles) and ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa), the latter with its own subset of Regional Agricultural Research Networks (RARNs). The four SROs (including one Sahelian: INSAH — Institut du Sahel) have formed a Forum for Agricultural Research in Africa (PARA).

In addition, there is the well-established CGIAR (Consultative Group on International Agricultural Research) system, established in 1971, with 16 international Agricultural Research Centres (ARCs) under its umbrella, whose mission it is to promote sustainable agriculture in order to achieve food security in developing countries. One such centre is the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, with its three ICRI SAT (International Crops Research Institute for Semi-Arid Tropics) campuses in Zimbabwe, Niger and Mali. Other examples are ILRI (International Livestock Research Institute) and ICRAF (International Centre for Research in Agroforestry), both located in Kenya.

**Regional research initiatives**

Strained relations are reported among the IARCs, SROs and NARS (Mrema 2002). They often compete for resources from donor agencies and their respective strategies are incongruent, with the IARCs and NARS focused on poverty eradication and the SROs on market and economic growth. The three sub-Saharan SROs (ASARECA, CORAF and
SACCAR) are receiving increasing funding from USAID, the EU, Danida (Danish International Development Assistance), SIDA (Swedish International Development Agency), CIDA (Canadian International Development Agency) and BMZ (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung). According to Mremma (2002) this indicates that the regional research approach is seen as more effective. The venerable CGIAR system is currently under review mainly because of declining support from donors and rising costs in running its 16 centres. (See also: DIAS Report No. 77 (2002) on The Role of Research in the Development of African Agriculture.) Organisations in a number of European countries, among them the UK, France, Germany, The Netherlands and the Nordic countries, support regional biotechnology collaboration with developing countries through other programmes.

South Africa: a Type I NARS country

Concerning the NAR systems, developing countries are broadly divided into three groups (Bayerlee and Fisher 2000 as cited in Danida Working Paper 2002). The first, Type I NARS, includes Brazil, China, India, Mexico and South Africa. South Africa is the only African country to qualify for this category, which has a strong capacity in plant breeding, biotechnology and molecular biology. Type II NARS countries have capacity in plant breeding and are able to apply molecular tools that have been developed elsewhere; they are in the process of building competence in molecular biology. Type III NARS countries, which include most in sub-Saharan Africa, have limited capacity and are largely dependent on the introduction and testing of cultivars from elsewhere. Many, though, have a growing capacity in tissue culture, which has become an integral component of plant breeding.

Although rated a Type I NARS country, the reality is that South African agricultural research, for which the ARC (Agricultural Research Council) has the major responsibility, is in decline (Financial Mail 2003). According to the same newspaper report, the ARC has lost the equivalent of 4 000 years of cumulative experience and skills over the past five years. In 2000/2001 alone, 40% of staff — that is, 62 PhD researchers— left. Ten years ago, four of the ARC’s 13 institutes (namely, Grain Crops, Vegetable and Ornamental Plants, Animal Nutrition and Products, and Agricultural Engineering), employed 262 researchers; at present they have 79. The Onderstepoort Veterinary Institute can no longer supply foot-and-mouth vaccine to neighbouring countries, which in the past also ensured South Africa with an effective buffer zone. Whatever the reasons for the decline in agricultural research, lack of government funding, which afflicts all countries in SSA, is one of them. However, if allowed to continue, this decline in research capacity could jeopardise South Africa’s status as a Type I NARS country and have disastrous consequences not only for a country called ‘Africa’s great black hope’ by The Economist (2001b), but also for the SSA region.

It is fortunate for South Africa that definitive molecular biology research of international quality is carried out by universities (e.g. Berger 2004) and several non-university institutes, which also serve as training centres for many post-graduate students and postdoctoral fellows from other African countries.

Historically, agricultural research in South Africa was almost exclusively aimed towards large-scale farmers, but since independence in 1994 it is the smallholder and subsistence farmer upon whom attention is deservedly being focused. The NAR equivalent in South Africa, the ARC, therefore has an important duty in the implementation of sustainable biotechnology in small-scale agriculture. Dearlove et al. (2004) describe the polyfarm system and how biotechnology might be integrated with it.

Biotechnology for Sub-Saharan Africa

Wambugu (1999) makes an eloquent plea as to why Africa needs agricultural biotechnology. Plant biotechnology (Figure 1) is the exploitation of available genetic knowledge obtained through functional genomics using the tools of gene transfer and molecular markers (Danida Working Paper 2002). In 2001, crop plants genetically modified for herbicide and insect tolerance were grown on 50 million ha worldwide, and according to the authors of that working paper, these two traits also have major significance for developing countries. However, only four crops make up the bulk of the transgenic crops, namely maize, cotton, soybean and oilseed rape. Herbicide resistance is the only genetically-engineered trait in the latter two, while in transgenic maize and cotton more than half is insect tolerant or has tolerance to both insects and herbicides.

The present commercial use of a restricted number of transgenic crops in the industrialised world is almost exclusively limited to the manipulation of a few input traits (such as herbicide, pest and disease tolerance mentioned above) in a very small number of commodity crops. Of the above-named four major transgenic crop species worldwide, only maize and cotton have any relevance in SSA. The more rad-

Figure 1: (Modified from Danida Working Paper 2002). Modern plant biotechnology is often regarded as synonymous with genetic modification using the tools of genetic engineering. Thus, plant biotech exploits genetic knowledge through technologies of gene transfer (transformation) and genetic maps (molecular markers), which in turn are used in specific, product-oriented applications. However, to arrive at the products, transgenic plants usually have to pass a tissue culture phase (Figure 2)
tical approach, namely genetic modification of output traits for industrial and pharmaceutical applications, such as specialised oils or edible vaccines, is not yet commercially viable (Murphy 2003). We suspect the strategy will be to incorporate these traits by genetic transformation into the relatively few already-commercialised crop species. Meanwhile, Africa abounds with native species that contain potentially valuable output traits (e.g. a variety of imbizas, the active substance PS7 in Hoodia spp. that suppresses appetite, and many other compounds of medicinal value that do not require the more radical approach.

For all its apparent benefits, biotechnology has suffered from bad publicity in Africa, not least due to one of the greatest public relations blunders by the agribusiness industry — their plans to introduce terminator gene technology. The latter is based on a set of genes that acts as a series of molecular switches that are triggered, for example, by chemical treatment of seed of GM plants carrying resistance genes to herbicides, insects, or disease, and which prevents the seed from germinating. The farmer who next season wishes to grow the plant with the same genetically-engineered traits must purchase fresh seed. In principle, this practice is not all that different from the current one in developed countries where growers every year buy new hybrid seed (e.g. maize, sugar beet) raised through conventional breeding rather than via genetic engineering. However, in spite of raising great interest in the biotechnology industry, the terminator technology caused such an outcry in society that in October 1999 a five-year moratorium was self-imposed on its development. Herbicide resistance, especially, is a contentious trait in the context of Africa, where most, if not all subsistence and smallholder farmers save seed from season to season (Modi 2004), sometimes to plant only a few rows of a particular crop, thus making the cost of the GM seed and the herbicide prohibitive, as well as the latter’s application almost totally impracticable (Van der Westhuizen 2004).

Biotechnology based on crop diversity and product orientation

Table 1 gives an indication of the wide variety of crop interests expressed by participants in two advanced tissue culture courses presented by UNESCO–BETCEN at the ARC's Vegetable and Ornamental Plant Institute near Pretoria (Bothma and Thompson 2004). Admittedly not a statistically significant sample and probably representing the major interests of the participants' institutions, the crop priorities nevertheless closely reflect those reported in a study commissioned by the Rockefeller Foundation (Biotechnology for African Crops 1999). Table 1 also indicates the more or less similar research aims of, and methods employed by, the participants. National research programme priorities in SSA consistently list banana/plantain, cassava, cowpea, maize, sorghum, millets, rice, sweet potato, groundnuts, beans and vegetables, and in the case of the Sahel, humid and sub-humid West Africa, yams, as high-priority food crops (Biotechnology for African Crops 1999). The crop diversity in SSA (Okole and Odhav 2004) argues against a commodity-based biotechnology in favour of one also based on the inclusion of a number of 'smaller', less commercial crops.

Brink et al. (1998) suggested the development of biotechnology in Africa would be best accomplished in phases: first a tissue culture phase, followed by the use of tools to improve selection and breeding, and lastly by developing transgenic capacity. In our view, it will be product-orientated biotechnology (Figure 2), that is, technologies based on tissue culture, molecular markers and biocontrol, that will be the most suitable and readily usable for SSA countries. However, to be successful, product-orientated biotechnology introduced to serve small-scale farmers (such as a conglomeration of polyfarms) will require bold and purposeful collaboration among government agricultural departments, international assistance agencies, regional biotech networks, universities and other capacity-building institutions, and last but not least, local communities.

African leadership will be the key to creating change and severing dependence on food aid (Blackie 2002). Eicher (cited by Blackie 2002) pointed out that the largely hidden food insecurity in Africa and the availability of food aid have led many African political leaders to view agricultural research as an activity to be financed by foreign aid. A recent FAO report on 'The state of food insecurity in the world 2003' includes the following statement: 'Bluntly stated, the problem is not so much a lack of food as a lack of political will' (http://bbc.co.uk./2/hi/health/3236364.stm).

**Table 1**: Crop interests expressed by participants in advanced tissue culture courses (November 1999 and March 2001) presented by UNESCO–BETCEN, South Africa. For banana read banana/plantain

<table>
<thead>
<tr>
<th>Country</th>
<th>Main crops of interest</th>
<th>Research aims</th>
<th>Methods used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cameroon</td>
<td>Banana, cocoyam, cassava</td>
<td>Disease resistance</td>
<td>Micropropagation, meristem culture</td>
</tr>
<tr>
<td>Ghana</td>
<td>Banana, cassava, papaya</td>
<td>Disease resistance, sex determination in papaya</td>
<td>Mutation breeding</td>
</tr>
<tr>
<td>Kenya</td>
<td>Millet, papaya, <em>Monling oleifera</em>, pyrethrum</td>
<td>Sex determination in papaya, micropropagation</td>
<td>Germplasm screening, micropropagation, rooting of cuttings, disease control</td>
</tr>
<tr>
<td>Malawi</td>
<td>Sweet potato, cassava, potato</td>
<td>Disease resistance</td>
<td>Meristem culture</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Banana, cassava, millet</td>
<td>Disease resistance</td>
<td>Tissue culture, molecular markers</td>
</tr>
<tr>
<td>South Africa</td>
<td>Maize, millet, sorghum</td>
<td>Transformation</td>
<td>Somatic embryogenesis for regeneration</td>
</tr>
<tr>
<td>Sudan</td>
<td>Banana, date palm, potato</td>
<td>Disease resistance, virus-free material</td>
<td>Micropropagation</td>
</tr>
<tr>
<td>Tanzania</td>
<td>Sisal, clove, cashew</td>
<td>Disease-free planting stock</td>
<td>Micropropagation</td>
</tr>
<tr>
<td>Uganda</td>
<td>Coffee, banana, cassava</td>
<td>Disease resistance and elimination</td>
<td>Micropropagation, tissue culture including meristem culture</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>Sweet potato, <em>Zizyphus</em>, millet</td>
<td>Disease-free planting stoch, hardwood cuttings</td>
<td>Nodal cuttings, micropropagation</td>
</tr>
</tbody>
</table>
in agriculture at present (Botha et al. 2004). Biocontrol is an area of immense potential (Korsten 2004).

**New Crops**

Many useful plant species in Africa can be regarded as ‘new’ crops and are sources of useful products, including medicinal compounds and nutraceuticals (Nigro et al. 2004). New crops may, however, have undesirable agronomic characters, such as awkward morphological architecture, asynchronous flowering, pod-shattering or low yields (Murphy 2003), that do not readily lend themselves to commercial exploitation. Murphy (2003) made the point that the focus on genomics, proteomics and bioinformatics may adversely affect funding for the biochemical and physiological research required to understand plant function under conditions of stress (Cowan 2004, Slabbert and Spreeth 2004, Vlijmen et al. 2004). In Africa, research into the development of new crops should be supported by public funding, as private, for-profit companies tend to regard this type of research as too long term and with uncertain rewards.

**Native plants for biotech development**

One should not raise expectations by publicising traits that exaggerate plant potential, but southern Africa in particular has a large number of low-acreage, indigenous species that contain valuable medicinal, dietary and nutritious compounds. Many of these species are relatively scarce and will not withstand unrestricted wild-harvesting. Because they are naturally-endowed with output traits, these plants do not need to undergo genetic transformation and they could, after regeneration by rooted cuttings (Negash 2004) or mass micropropagation (Mycok et al. 2004), be exploited in smallholder agriculture for the production of special products export (so-called molecular pharming). Likely candidates for the investment of biotech research in the future, therefore, are existing or potentially economically important food, fibre, medicinal and ornamental plants, and especially those that require intensive ex situ and in situ conservation, or — in many cases — both. As an illustration, we have selected only five species (for countless other examples see Fennell and Van Staden 2004, Nigro et al. 2004, Niederweiser 2004, Van Wyk and Gericie 2000).

**Cereals**

Africa is home to more indigenous cereal species than any other continent. The most important are sorghum (Sorghum bicolor (L.) Moench.) and pearl millet (Pennisetum glaucum (L.) R.Br. subsp. glaucum). Grains of lesser importance include Eleusine coracana (L.) Gaertn.; the nutritious Digitaria exilis Stapf (finger millet, fundi or fonio), rich in cysteine and methionine and which makes a tasty porridge; Eragrostis tef (Zucc.) Trotter (tef), Ethiopia’s most important grain, used to make fermented bread, and which contains high iron levels and balanced amino acids; and the independently-domesticated West African rice Oryza glaberrima Steudel (red rice). In Lost Crops of Africa (1996) it is highlighted that introduced cereals have replaced several African species, and an illogical and ill-conceived inclination exists

**Marked-assisted selection**

Murphy (2003) stressed that biotechnology is much more than the production of Genetically-Manipulated Organisms (GMOS). Conventional tissue culture techniques such as mass micropropagation of selected genotypes of species that are normally vegetatively propagated, the production of virus-free foundation stock, biocontrol using effective and environmentally friendly agents, as well as the use of molecular markers, will have the greatest short term impact in Africa. There is no reason why the successful use of marker-assisted selection and breeding, whereby useful traits can be linked with specific markers (Butterfield et al. 2004), cannot be applied in Africa, even if the scale of agriculture differs vastly from that in the industrialised world. New marker technology has become considerably cheaper and easier to use and can be applied to assist in the breeding of non-commercial crops that are essential in providing food security in Africa. According to Murphy (2003), marker-assisted selection is by far the most significant application of biotech
that considers introduced crops superior and indigenous ones obsolete or inferior. It is also pointed out that the most frequent criticism concerns the native crops’ low yield, disregarding the fact that most are cultivated on marginal lands without technological inputs. In reality, under poor conditions ‘African grains often out-yield the best products of modern science’. Pearl millet is an example of such a grain crop.

Pearl millet
Pearl millet is a rapid-growing plant that utilises soil moisture efficiently and thrives on light soils in dry regions. It is grown extensively in the drier areas of the SSA, including northern Nigeria and northern Namibia, and is a very important food crop in the subsistence agriculture of the Sahelian zone of West Africa (rainfall 250–800mm) where it is cultivated on 14 million ha (Kumar 2003). Pearl millet (Figure 3) is the world’s sixth most important cereal grain. Although the species is notably hardy, research such as that undertaken at ICRISS–Niger, focuses on aspects such as increased grain and biomass yield, disease and Striga resistance, and hybrid breeding. In collaboration with other laboratories, molecular marker techniques have been used to identify genes for resistance to Sclerospora graminicola, the fungus that causes downy mildew.

One factor that limits grain yields is the presence of mimetic weedy forms; domestic pearl millet is able to hybridise spontaneously with wild species to produce intermediate weedy hybrids. For instance, P. glaucum subsp. stenostachyum is the result of a cross between the domestic P. glaucum subsp. glaucum with the wild P. glaucum subsp. monodii. These spontaneous weedy mimetic forms, called shibras (in the Hausa language), have a low production of small grains and are prone to shattering thereby reducing yields. At ICRISS–Niger (Kumar 2003), S. progeny testing and selection are being used in an attempt to eliminate weedy forms. Fertile, transgenic pearl millet plants have been produced (Girgi et al. 2002, Goldman et al. 2003) and in South Africa work is focused on the introduction of resistance to downy mildew in breeding lines.

Aloes
Aloes are a distinctive feature of the African landscape. The Asphodelaceae, to which aloes and their relatives belong, includes 10 genera and over 350 species (Leistner 2000). They have a long history of use in Africa, for fibre, medicines, cosmetics, fuel, beverages, and as ornamental garden plants (Van Wyk and Smith 1996). Indeed, Aloe ferox Mill. is among the few plant taxa recognisable in southern African San rock art (Van Wyk and Gericie 2000), bearing testimony to its cultural importance (Figure 4). Today, A. ferox and A. vera (L.) Burm.f. are among the world’s most widely-used medicinal plants, and both form the basis of large industrial markets for their natural products (Newton and Vaughn 1996, Van Wyk and Gericie 2000).

Unscrupulous wild-harvesting and trade in local and international markets have rendered many African members of the Asphodelaceae endangered and threatened with extinction (Newton and Chan 1998). Reduced availability and economic value make aloes attractive subjects for horticultural and natural products research, and investments of biotechnology in their cultivation and phytochemical development are set to continue.

Aloe polyphylla
Aloe polyphylla Schönland ex Pillans (Asphodelaceae), endemic to a narrow mountainous range in the small landlocked Kingdom of Lesotho in southern Africa, is a likely candidate for biotech investments. Its distinct spiral leaf arrangement (Figure 5), and the difficulty with which it is cultivated, makes it a coveted horticultural subject. As the national flower of Lesotho and vulnerable to extinction (Tarukdar 2002), the future of the taxon is of socio-economic significance, as well as conservation concern. In situ conservation is threatened by illegal wild-harvesting and is compounded by poor seed set due to the endangered status of its pollinator, the Malachite sunbird (Chukwujekwu et al. 2002). A. polyphylla may be cultivated from seed or propagated by occasional vegetative offshoots, but specific soil and moisture requirements limit its survival in cultivation (Van Wyk and Smith 1996). Micropropagation, therefore, has distinct advantages for the rapid multiplication of material from limited parent stock. A micropropagation protocol using whole plantlets or leaf explants obtained from seeds germinated in vitro has been established to produce clonal propagules with 98% survival following hardening off (Abrie and Van Staden 2001, Chukwujekwu et al. 2002). Mass produced plants can be used to meet demands for A. polyphylla as a popular ornamental, and to facilitate breeding or genetic manipulation experiments seeking to improve its viability in cultivation.

Kniphofia
The genus Kniphofia, closely related to Aloe and well known for its ‘red hot poker’ inflorescences in African scenery (Figure 6), presents another important conservation challenge in the face of extensive wild-harvesting and habitat disturbance. Plant collectors favour the group for its non-succulent leaves and spectacular inflorescences; many members of the genus are also used medicinally in Africa. Effective micropropagation protocols have been established for the narrowly distributed southern African K. pauciflora Baker (McAlister and Van Staden 1996) and K. leucocephala Baijinhath (McCcartan and Van Staden 2004, McCartan et al. 2003). Others, such as the critically endangered Swaziland endemic K. tysonii Baker subsp. lebomboensis Codd and K. umbrina Codd (Diamini and Diamini 2002) would benefit from similar research attentions. Like A. polyphylla, micropropagation would enable breeding or genetic manipulation for improved varieties, and provide mass propagated stock that could serve as an effective alternative to wild-harvested material.

Devil’s claw
Besides Aloe vera and A. ferox, numerous African traditional medicines have assumed commercial importance in modern times, and present great potential for development using biotechnology. Harpagophytum procumbens (Burch.) DC (Pedaliaceae), the devil’s claw (an appropriate description of its spiny fruit), is one such example from the arid regions of southern Africa, and has gained great economic importance.
Figure 3: A field of pearl millet at ICRASAT–Bulawayo, Zimbabwe. Photograph G Bothma

Figure 4: Aloes have been used in Africa for centuries. *Aloe arborescens* (foreground) and *Aloe ferox* (background) are among the most useful. Photograph N Crouch

Figure 5: *Aloe polyphylla* is a valuable horticultural subject, popular for its spirally-arranged leaves. Photograph N Crouch

Figure 6: *Kniphofia* spp. are favoured for their ‘red hot poker’ inflorescences. Photograph N Crouch
in recent decades. Tonics of the fruit and tubers of both *H. procumbens* and *H. zeyheri* Decne. are traditionally used to treat a variety of ailments (Van Wyk and Gericke 2000), for which their therapeutic value has been confirmed in some cases by pharmacological investigation. A range of bioactivity, including analgesic, anti-inflammatory and cardiovascular activity has been reported, as well as certain pharmacokinetic properties and active principles (e.g. Circosta et al. 1984, Lanhers et al. 1992, Soulimani et al. 1994, Baghdidian et al. 1997, Loew et al. 2001).

Some 700 tons of *H. procumbens* are exported from southern Africa annually (the principal producer is Namibia) (CITES Plants Committee 2002). Most material is wild-harvested and questions of sustainability have been raised in the face of escalating European and American market demands. Although *H. procumbens* is heavily utilised in some areas, trade does not affect it throughout its range (CITES Plants Committee 2002). Crop production in some regions represents an alternative source of both plant material and income to harvesters (Van Wyk and Gericke 2000, ResourceAfrica 2003). Micropropagation protocols for rapid, high-yielding multiplication in vitro have been reported by Levielle et al. (2000) and Shushu (2001), and circumvent the problem of poor seed germination in the species. The use of clonal (micropropagated) material is preferable for phytochemical uniformity and quality control.

Understanding of its bioactivity, natural products chemistry and in vitro propagation makes *Harpagophytum* ideally suited to future development. Application of biotechnology in a value-adding process has great potential to aid the establishment of African taxa such as the devil’s claw in international markets and industries.

**Prunus africana**

By enhancing the economic values of useful taxa, biotechnology can substantiate the need for their conservation. Additionally, it can contribute directly by providing high-value products as alternatives to those harvested in the wild. For these reasons, biotechnology investment in *Prunus africana* L. (Rosaceae), the single member of the genus native to Africa, would be relevant to its future. Like *H. procumbens*, its modern economic importance arose from traditional use. An extensive literature documents its history, management and properties (O’Brien and Youde 1999).

The use of *P. africana* bark by Europeans to treat urinary complaints, on advice from local traditional healers in Natal, dates to the 1700s. Today it is among the most-used therapies for prostate enlargement, and market demands are expected to double or triple within the next decade (Cunningham and Mbenkum 1993, Prunus Net 2003). The European pharmaceutical industry is supplied almost exclusively by wild populations, principally in Cameroon, Madagascar, Kenya and Equatorial Guinea. Despite CITES Appendix II listing and legislation to ensure sustainability, the rate at which bark is harvested far exceeds that of re-growth (Cunningham and Mbenkum 1993, George et al. 2001, Prunus Net 2003).

In a scenario similar to that described for *Harpagophytum*, biotechnology could be applied to the mass propagation *P. africana* as an alternative to wild-harvesting. However, trees are unattractive crops to farmers with limited resources, as the maturation period — up to 20 years for *P. africana* — is non-productive (Grace et al. 2002). Besides plantations, enrichment planting to replenish seedling populations in indigenous forest, and small-scale farming, could significantly impact on the sustainability of *P. africana* bark (Stewart 2003). Biotechnology may be the key to such longer-term solutions. Biotechnologies have been used to answer questions regarding the population genetics of *P. africana*, and have been suggested for gene banking to ensure ex situ conservation (Stewart 2003). Although *P. africana* is among those useful African plants that do not require transformation to ensure their future economic importance, the bioactivity and chemistry of *P. africana* bark are relatively well understood and, with a protocol for in vitro propagation, the species would be well disposed to manipulation. Pharmacological activity in *P. africana* is ascribed to three compound classes (phytosterols, ferulic esters and pentacyclic triterpenes (Stewart 2003)) whose production could be upregulated. Other traits to improve the agricultural viability of *P. africana* for African farmers may include enhanced phytochemical yields and harvest biomass as a result of additional plant parts (besides bark) being induced to synthesise the natural products for which *P. africana* is exploited. In South Africa, at least two important medicinal plant taxa — *Ocotea bullata* (Burch.) Baill. (Lauraceae) and *Warburgia salutaris* (Bertol.f.) Chiov. (Canellaceae) — are managed by traditional healers to produce coprice for high leaf yields, that are used with improved sustainability, instead of bark (Grace et al. 2002). Biotechnology holds promise for the future of *P. africana* as one of Africa’s important plant exports.

**Conclusion**

Much of the recently developed plant biotechnology contains aspects that may be important for increased food security and poverty alleviation in SSA, the only region where hunger and child malnutrition continue to increase and where per capita agricultural production has declined since the late 1960s. Whether or not plant biotechnology can be implemented and sustained will depend on two principal factors. First, implementation should take account of the conditions under which small-scale farmers and poor consumers live and work, and its application should be orientated towards regions and their diverse crops. This would argue for a product-orientated biotechnology that in the first instance would involve tissue culture-, molecular marker- and biocontrol-based techniques. Work on large commodity crops should not be carried out to the exclusion of less commercial, indigenous ones. Already, a biotech framework exists in the form of sub-regional and other organisations. Second, in order to sustain plant biotechnology and help break the cycle of dependence on food aid to many SSA countries, action within an appropriate framework of agriculture and biotechnology policy has to be the responsibility primarily of governments and their leaders.

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