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BIOTECHNOLOGY FOR CASH CROPS OF DEVELOPING COUNTRIES: OPPORTUNITIES, PROSPECTS AND THREATS

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Introduction

Agriculture is very important to the economies of most of the developing countries (DCs) of the world and, in some instances, constitutes their main economic activity. Although there is a need for ever-increasing food production in these countries, the production of cash crops continues to be relevant for the generation of vital export earnings, economic growth and employment creation (18).

The major cash crops of DCs are generally those that are produced largely or exclusively for export and include coffee, cocoa, palm oil, rubber, sugarcane and tea. However, several other crops have assumed importance as exports from various DCs. They include avocado, banana, cotton, various nuts (e.g. cashew and pistachio), coconut, citrus, date palm, fresh vegetables, groundnuts, jute, litchi, mango, pineapple, pyrethrum, spices (cardamon, pepper, pimento, vanilla), ornamental flowers, papaya, soyabean, sisal, sunflower, tobacco, and timber (1,7,12).

Prior to 1950, the DCs had significant research programmes for the improvement of the so-called "colonial trade crops" such as sugarcane, tea, coffee, cocoa, cotton and rubber (11). However, after independence, food crops were accorded greater attention although research on cash crops has continued to varying degrees due to their economic importance. While significant advances in the production of cash crops have been achieved through the use of conventional breeding and the adoption of improved agronomic practices, several constraints still limit increased and sustainable production. Biotechnology offers new and exciting opportunities, particularly for the amelioration of important constraints which have proved intractable to conventional techniques (9,13,15,21,28,30,34). It must, however, be viewed as a supplementary tool rather than as a substitute for conventional approaches to improved crop production.

The potential role of biotechnology includes the following:

- Production of disease-free planting material
- Rapid propagation of superior genotypes
- Reduction of breeding time
- Development of transgenic plants with resistance or tolerance to important diseases, pests and abiotic stresses
- Transfer and storage of germplasm
- Genome mapping to facilitate selection
- Development of herbicide-tolerant transgenic plants which may allow for more effective and widespread weed control
- Development of diagnostics for pathogen detection

The state-of-the-art in biotechnology for important cash crops is shown in Table 1; its possible applications and suitability for the amelioration of major constraints are illustrated in Table 2.

Table 1. Biotechnology state-of-the-art for major cash crops produced in developing countries

Crop	Micro-propagation and disease elimination	Regeneration	Transform-ation	Potentially useful transgenics	Mapping
Avocado	+	-	-	-	-
Banana	+++	+	+	-	+
Cardamon	+	-	-	-	-
Citrus	+++	-	-	-	-
Cocoa	+	-	-	-	-
Coconut	+	+	-	-	-
Coffee	++	+	-	-	-
Cotton	na	+	+	+	+
Date palm	+	++	-	-	-
Groundnuts	na	+	+	-	+
Mango	+	+	-	-	-
Oil palm	+++	++	-	-	-
Pepper	+	-	-	-	-
Pineapple	+	+	-	-	-
Pyrethrum	++	-	-	-	-
Rubber	++	+	-	-	+
Soyabean	na	++	++	+	+
Strawberry	++	+	+	-	-
Sugarcane	++	-	+	-	-
Sunflower	na	+	+	-	-
Tea	+	-	-	-	-
Tobacco	na	+++	+++	+	+
Trees (forestry)	+	+	+	-	-
Vanilla	+	-	-	-	-

Codes: na, not applicable;
-, not developed; +, just beginning; ++, widely used; +++, routine

Table 2. Major constraints, conventional solutions, potential application and suitability of biotechnology solutions.

Crop	Constraint	Conventional solution	Biotechnology solution	Suitability
Avocado	Black spot	heat treatment	not available	-
Banana	Propagation	vegetative shoots	micropropagation	++
	Black Sigatoka	breeding; chemicals	not available	++
	Panama disease	breeding; chemicals	not available	++
	Fusarium wilt	breeding	not available	++
	Nematodes	nematicides	micropropagation	++
	Viruses	none	micropropagation; CPMP	+
Citrus	Propagation	grafting, seeds	shoot-tip grafting	-
	Viruses	polyembryonic seeds	shoot-tip grafting	+
Cocoa	Propagation	seeds; rooted cuttings	micropropagation	++
	Viruses	not available	micropropagation	++
	Moniliasis	breeding; chemicals	not available	+
	Black pod	chemicals	not available	-
	Canker	chemicals	not available	-
	Witches broom	chemicals	not available	++
Coconut	Propagation	seed	not available	+
	Lethal yellowing	breeding	diagnostics	++
Coffee	Propagation	seed, vegetative	micropropagation	++
	Berry disease	breeding	not available	++
	Rust	breeding	not available	+

Suitability: -, not suitable; +, suitable; ++, highly suitable

CPMP: virus coat protein-mediated protection

Table 2 (continued). Major constraints, conventional solutions, potential application and suitability of biotechnology solutions.

Crop	Constraint	Conventional solution	Biotechnology solution	Suitability
Cotton	Verticillium wilt	breeding	not available	+
	Bacterial blight	breeding	not available	-
	Insect pests	chemicals	Bt and CpTI transgenics	++
Date palm	Propagation	seed, vegetative	micropropagation	++
	Tracheomycosis	not available	micropropagation	++
Groundnuts	Viruses	not available	CPMP	++
	Leaf spots	breeding	not available	-
	Rust	breeding	not available	-
Mango	Propagation	Vegetative buds	not available	-
Oil palm	Propagation	seed	micropropagation	++
Pepper	Viruses	not available	micropropagation; CPMP	++
Pineapple	Propagation	vegetative suckers	micropropagation	++
Pyrethrum	Propagation	vegetative	micropropagation	++
Rubber	Propagation	seed, vegetative buds	micropropagation	++
	Leaf blight	breeding	not available	+

Bt: Bacillus thuringiensis

CpTI: Cowpea trypsin inhibitor

Table 2 (continued). Major constraints, conventional solutions, potential application and suitability of biotechnology solutions.

Crop	Constraint	Conventional solution	Biotechnology solution	Suitability
Soyabean	Nitrogen	fertiliser	improved inoculant	++
	Web blotch	breeding	not available	-
	Insect pests	chemicals	Bt transgenics	+
Sugarcane	Propagation	Vegetative cuttings	not available	-
	Loose smut	breeding; chemicals	not available	-
	Fiji disease	breeding; chemicals	somaclonal variants	+
Sunflower	Leaf spots	breeding	not available	-
	Sclerotinia	breeding	not available	-
Tea	Propagation	stem cuttings	micropropagation	+
	Root rots	chemicals	not available	-
Tobacco	Virus diseases	breeding	CPMP	+
	Alternaria blight	breeding; chemicals	not available	-
	Wildfire	breeding; chemicals	BSP transgenics	+
	Blue mould	breeding; chemicals	not available	+
	Nematodes	breeding; chemicals	not available	+
	Insect pests	chemicals	Bt and CpTI transgenics	+
Trees	Propagation	seeds, vegetative	micropropagation	++
Vanilla	Propagation	stem cuttings	micropropagation	+

BSP: Bacterial self-protection

Production of disease-free planting material

Insidious and debilitating systemic infections by viruses, viroids, fungi, bacteria and mycoplasma-like organisms (MLOs) afflict several crops in DCs and are particularly serious in those which are vegetatively propagated. Nematode infestations also pose problems in some crops such as bananas. Unchecked, these infections pose a serious threat, particularly for the majority of DC farmers who continually produce their own planting material. Biotechnology offers an appropriate and simple solution to this problem through the development of commercial-scale in vitro techniques for the elimination of systemic infections and the production of pathogen-free planting material (25). Shoot- and meristem-tip culture have proved successful in banana, date palm, pineapple and rubber but continue to be problematic for cocoa, coffee, coconut, oil palm and pepper (2,5,25,27,30,42). In citrus, shoot-tip grafting and polyembryonic seed production has obviated the need for meristem- and shoot-tip culture (30). Regeneration through organogenesis or somatic or zygotic embryogenesis offers considerable prospects for several crops if it can be developed to a commercial scale (34). In general, the development and application of in vitro technology for pathogen-elimination is within the reach of most DCs and could have enormous implications for crop production.

Rapid propagation of superior genotypes

Micropropagation of elite and pathogen-free genotypes is most applicable to species which are either perennial, sterile, outcrossed and therefore highly heterozygous, or suffer from persistent systemic infections. A variety of techniques including meristem- and shoot-tip culture, enhanced precocious axillary shoot formation and culture, organogenesis and somatic embryogenesis have been developed for banana, cardamon, chrysanthemum, date palm, oil palm, pineapple, pyrethrum and rubber (25,27,30,34). While significant progress in micropropagation has been made in other crops such as cocoa, coconut, coffee, mango, pepper and some trees (2,19,30,34), commercial-scale operations for these crops are yet to be achieved. The use of a liquid cell-culture bioreactor system based on somatic embryogenesis is potentially the most promising and rapid technique but is still being developed for banana, pineapple, coffee and ornamental palms (31). Micropropagation, coupled with pathogen elimination where appropriate, offers immense prospects for increased and sustainable crop production in DCs. Its modest technical requirements and low cost relative to other biotechnological techniques make it particularly suitable and cost-effective. However, the clonal fidelity problems encountered in banana, coconut and oil palm (27,30,34) warrant careful consideration during the commercialisation of micropropagation systems.

Generation of Genetic Variation

The production of somaclonal variants may be useful for the development of novel genotypes with resistance to biotic and abiotic stresses, particularly if such traits cannot be found in germplasm collections and wild relatives. However, although potentially useful variants for disease resistance have been obtained in sugarcane, tobacco and other crops (31,34), little progress has been made in the development of novel genotypes for commercial production.

Transgenic resistance/tolerance to diseases, pests and abiotic stresses

Transformation with reporter or potentially useful genes has now been achieved in several crops (14,15,16,20) and will probably become more widespread due to the use of biolistic techniques. However, the unavailability of efficient regeneration techniques will likely continue to be the main obstacle to the widespread use of recombinant DNA technology for crop improvement.

Transgenic plants carrying novel Bacillus thuringiensis (Bt) genes, proteinase inhibitors, viral coat-protein genes and bacterial self-protection (BSP) genes are likely to have a significant impact on pest and disease control, particularly within the context of reduced pesticide usage and sustainable agricultural production (4,5,6,14,15,16,20,24). While the technology is yet to be commercialised in developed countries, it appears very promising although it should be noted that it is unlikely to be entirely problem-free. If commercially successful, and it can be transferred to, or developed in DCs, this technology could alleviate important pest and disease problems (Table 2), reduce pesticide usage and also result in significant savings of foreign currency which would otherwise be used to procure pesticides from developed countries. Advances in the development of salinity-tolerant transgenic plants (33) are also of importance because abiotic stresses pose a major limitation to increased crop production in several DCs. However, DCs will have to wrestle with the problems of high cost, expertise demand, biosafety and proprietary protection if this technology is to be developed locally or transferred from developed countries. It is also important that DCs take cognisance of the Bt resistance "breakdown" problems that are looming in developed countries and attune themselves to the need for "resistance management" and rational implementation of transgenic technologies.

Reduction in breeding cycle

Long generation turnover time and slow propagation of improved genotypes pose problems in the breeding of coffee, cocoa, coconut, rubber and trees (1,30,34). Tissue culture techniques such as anther culture and micropropagation offer viable solutions and significant progress has already been made in several crops (30,34). Furthermore, biotechnology can expedite the genetic improvement of crops in which sexual incompatibility is a barrier to recombination and germplasm usage.

Germplasm Storage

In-situ germplasm conservation of perennial crops can be very costly, demanding of space and risky due to exposure to disease. Tissue culture and cryopreservation offer possible solutions to these problems for crops such as banana, coffee, cocoa, oil palm, rubber, mango, avocado, pepper and sugarcane (36). However, although appropriate techniques have been developed for some of these crops, the feasibility and suitability of the technology remains questionable.

Genome Mapping

The detailed mapping of plant genomes by Restriction Fragment Length Polymorphisms (RFLP) and Random Amplified Polymorphic DNA (RAPD) techniques is considered to hold enormous promise for the genetic improvement of various crops (32,37). Potential practical applications of this technology include detection of important genes and improved selection for traits which are difficult or very demanding to score. Genes of interest would include those for disease resistance, quality attributes and quantitative traits such as yield. However, while the technology is fairly advanced for crops such as cowpeas, groundnuts, soyabeans and maize, very little progress has been made in the major cash crops of DCs. Although the technology is already being used in some breeding programmes in developed countries, it is yet to be become routine due to its high cost and expertise requirements. Furthermore, the validity of the technique for the manipulation of important quantitative trait loci (QTLs) has also been questioned (10). Hence, although it appears promising, it is as yet unproven for QTLs (10) and presently of limited value to DCs. Given that there are other more pressing problems, the benefits of genome mapping presently appear questionable and it is perhaps best left to developed countries which can afford it.

Herbicide Tolerance

Genetic engineering of herbicide tolerance into crops such as maize, soyabean and tobacco ranks as one of the most important but highly controversial achievements of advanced biotechnology

(17,38). Although commercial production of transgenic plants with tolerance to more effective and supposedly environmentally-friendly herbicides is yet to become a reality, it is very likely that this technology will have major implications for high-input agriculture in developed countries. For DCs, the technology may be useful only for plantation crops or well-to-do farmers who normally use herbicides.

Diagnostics

Effective disease prevention and control is dependent upon precise identification of the causal organism. Although the diagnosis of most of the important diseases is not very difficult, some debilitating and sometimes unknown diseases continue to elude pathologists working in DCs. For viral diseases, the major limitations are inadequate training in virology, unavailability of ready-to-use test kits and the high cost of appropriate antisera. Even when test kits are available, strain differences may still hinder precise pathogen identification. Diagnosis of diseases caused by MLOs is more demanding although some progress is being made for important diseases such as lethal yellowing in coconut (3). In general, the ready availability of improved diagnostics could make a significant contribution to the production of some cash crops, particularly if combined with pathogen-elimination techniques, micropropagation and sanitation.

Biotechnology threats

The threats posed by biotechnology to cash crop production include the following:

- Substitution of vanilla, pyrethrum, some oilseed crops, cocoa butter and sugarcane by the biotechnology-based products of developed countries (5,21,23,26,29)
- Marginalisation of resource-poor farmers and smaller producing countries who are unable to capitalise on biotechnology
- Reduction in the biodiversity of crops due to widespread adoption of improved and rapidly propagated genotypes
- Increase in the genetic vulnerability of crops to pests and diseases due to widespread dependence on limited protective measures such as Bt transgenics
- Environmental degradation and negative impacts on sustainable agriculture due to more widespread and increased use of herbicides on transgenic herbicide-tolerant genotypes (17)
- Overproduction and consequently lower pricing due to rapid and widespread adoption of improved genotypes

The most publicised negative effect of biotechnology relates to the substitution of sugarcane with high-fructose syrup (HFS) produced from maize (5). Possible substitution of vanilla, pyrethrum, cocoa butter and some oils is receiving increasing attention (5,29) but is yet to become a reality. It is also argued that the worldwide shift to natural products coupled with their unique and complex characteristics will counteract substitution. Looming pest resistance to widely promoted Bt transgenics is of considerable concern (5). Therefore, as DCs ponder over the development, application and benefits of biotechnology, it is essential that they also consider and plan for possible negative impacts.

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