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Review

Biotechnology as a veritable tool for improved and sustainable sugar cane production in Nigeria and Northern African Countries: A review

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The application of biotechnology in the modification of organisms or organisms' by-products for specific use formed the basis of learning about crop variety improvement, crop pests and diseases management which underpinned the development of treatments. In sugar cane cultivation, biotechnology has produced a significant effect on the improvement of cane quality, reduced cane losses to diseases and pests and alleviated the chemical input of weed control methods which has the advantage of reducing environmental degradation. Through biotechnology, farmers have raised improved and high-yielding sugarcane crops, used organisms or their by-products to fertilise, adapted to given agroecology and controlled pests and diseases. Although, biotechnology alone cannot solve all problems associated with sugar cane production in Nigeria and other Northern African countries; however, it has the potential to address specific problems in sugar cane productivity such as improved yield, increased resistance to drought, pests and diseases, diversified techniques for weed management, enhanced nutritional value of the sugar produced from the high productivity sugar cane, reduced environmental impacts of sugar cane production, reduced post-harvest losses and enhanced market competitiveness. The limiting factors to the ability of Nigeria and North African countries to benefit from advances in modern biotechnology are the lack of scientific and technological capacity and the low level of development in the biotechnological enterprise. The challenge, therefore, is how to effectively harness and apply the cluster of techniques that comprise biotechnology to radically transform sugarcane farming systems in these countries.

Keywords: Sugarcane, pests and diseases, biotech-crop, improved productivity.

INTRODUCTION

Sugar cane is a member of the genus, *Saccharum* and the family, Gramineae. Varieties of sugar cane are highly heterogeneous and generally multiplied vegetatively by stem cuttings (Richard, 2009a). The time required and the continuous contamination by systemic diseases constitutes a serious impediment to multiplying elite genotypes of sugarcane varieties in the open field. Thus, meeting the rising challenges and increasing demand for improved sugar cane productivity will require the deployment of biotechnological tools (Richard, 2009a). The concept of biotechnology encompasses a wide range and history of procedures for modifying living organisms according to human purposes - going back to domestication of animals, cultivation of plants, and improvements to these through breeding programmes that employ artificial selection and hybridization

(Kingsbury, 2009). Over time, biotechnology has formed the basis of learning about crops and diseases and this has found extensive application in sugarcane production and it has also underpinned the development of treatments (Ming *et al*., 2005, Abah *et al*., 2010).

According to United Nations Convention on Biological Diversification, biotechnology refers to any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" (UN, 1992). Although not normally thought of as biotechnology, agriculture clearly fits the broad definition of "using a biotechnological system to make products" such that the cultivation of plants may be viewed as the earliest biotechnological enterprise (Ming *et al*., 2005). The processes and methods of agriculture have been refined by other mechanical and biological sciences since its inception. Through early biotechnology, farmers were able to select the best suited and highest-yield crops to produce enough food to support the growing population (Ming *et al*., 2005).

Throughout the practice of agriculture, farmers have inadvertently altered the genetic compositions of their crops by introducing them to new environments and breeding them with other plants - one of the first forms of biotechnology. Specific organisms and organisms' by-products were used to fertilise, restore nitrogen and control pests and diseases (Ming *et al*., 2005). Thus, for thousands of years, humans have used selective breeding, mating organisms with desirable characteristics to produce offspring with the same characteristics (Thieman and Palladino, 2008). This is primarily directed towards improving the production of crops and livestock to enhance food availability.

The application of biotechnology in sugar cane cultivation will produce a significant effect on improvement of cane quality, reduce cane loss to diseases and pests and alleviate the chemical input of weed control methods which has the advantage of reducing environmental degradation (Chondler and Dunwell, 2008). More importantly, this will reinvigorate the activities of the sugar industry in Nigeria and other North African countries. This review defines the potential areas where biotechnological tools will be used to improve the productivity of sugar cane in Nigeria and North African countries.

SUGAR CANE AGRICULTURE AND CHEMICAL PESTICIDES APPLICATION

Modern agronomy, plant breeding, pesticides and fertilisers and the technological improvements have sharply increased yields from cultivation and caused widespread ecological damage and negative human health effects (USEPA, 2006). The services sector has overtaken agriculture as the economic sector employing the most people worldwide (ILO, 2009). Despite the size of its workforce, agricultural production accounts for less than 5% of the gross world product, that is, an aggregate of all gross domestic products. Since its development roughly 10,000 years ago (Richard, 2009b), sugar crops agriculture has expanded vastly in geographical coverage and yields. Throughout this expansion, new technologies and new crops were integrated. Following the domestication of several major crops and sugar cane, plant improvement was painfully slow because people remained unaware that humans could make changes in living organisms (Kingsbury, 2009).

Agricultural pesticides are the backbone of efforts that have produced a stunning increase in farm produce over the last four decades. Since the end of World War II, the emergence of synthetic chemical pesticide industry offered farmers what appeared to be miraculous control of pests and enhanced sugar cane and other crop yields (USEPA, 2006). Considering the impact of chemical pesticides on agro-produce, they seemed to be truly miracle pesticides.

The application of herbicides in sugar cane production has greatly reduced the high demanding manual weeding (Ochem, 2003). These are some of the areas where biotechnological tools have been used to improve crop productivity including sugar cane in a sustainable manner. Another area where biotechnological tools have been used effectively is on the effect of the new pesticides on the attitude of those who controlled pests which were revolutionary. Where farmers had formerly talked of controlling pests, they now talked of "eradicating" pests (USEPA, 2006). People envisioned the extermination of entire species of pest, plant pathogenic organisms, and weeds and expected 100% kill from their pests control actions (USEPA, 2006). With such dramatic success, it is easy to understand why the use of pesticides caught on so quickly. Indeed, in the decades after the war, pests control became predominantly a matter of chemistry. Where management of pest problems previously relied on ecological principles, sugar cane farmers were then encouraged to abandon many preventive/control measures like rotating crops, simultaneous cropping, and encouraging natural enemies of pests (USEPA, 2006) which are biotechnological tools. Not only were farmers transformed by the chemical revolution; public agricultural institutions, state agricultural institutions, and agricultural universities have shifted their research and education mission from agriculture as a biological and ecological activity to one based on chemicals. The results are the widespread adoption of chemical pesticides with a significant contribution to unprecedented increases in crop yields, but which also resulted in the poisoning of farmers and rural residents, contamination of food and drinking water, destruction of wildlife habitats and decimation of wildlife (USEPA, 2006, Chondler and Dunwell, 2008). This has thus given rise to a search for less chemical dependent agriculture.

BIOTECHNOLOGY AND SUSTAINABLE SUGAR CANE PRODUCTION IN NIGERIA AND NORTH AFRICAN COUNTRIES

Generally, crop biotechnology has been practised by mankind for thousands of years, since the beginning of civilisation. Sugarcane breeding and alteration practices have changed the genetic make-up of cane to develop more beneficial characteristics for humans. For example, viable seeds, drought tolerance, resistance to pests and diseases, nutritional quality, high yielding varieties among others (Richard, 2009a). Significant advances in sugarcane breeding gave plant breeders a better understanding of cane genetics and brought great insights to the techniques utilised by them. The essential breeding techniques include a selection of cane varieties with desirable traits, self-pollination and cross-pollination, as well as molecular techniques that genetically modify the organism. Thus, through careful selection and breeding, domestication of sugar cane has, over the years increased yield, improved disease resistance, drought tolerance, eased harvest and improved the taste and nutritional value of cane varieties, thus producing enormous effects on the characteristics of sugar cane and the prospect of sugar industry (Richard, 2009a).

The technique of biotechnology alone cannot solve all problems associated with sugar cane agricultural production and sugar cane improvement; however, it has the potential to address specific problems such as increasing sugar cane productivity, increasing cane resistance to drought, pests and diseases, diversifying techniques for loss and promoting market competitiveness (Abah *et al*., 2010). Thus, the cluster of techniques that comprise biotechnology can if effectively harnessed and applied, radically transform sugarcane farming systems in Nigeria and other North African countries.

The main limiting factors to the ability of the developing countries especially Nigeria and Northern Africa to benefit from advances in modern biotechnology are the lack of scientific and technological capacity and the low level of enterprise development in most of these countries (James, 2008). Although biotechnology applies across a number of fields, agricultural biotechnology, however, appears to be the most crucial tool for increased sugar cane production for African countries and especially for resource-poor farmers whose sole livelihood depends on agriculture. The biotechnology studies including both main branches of tissue culture and DNA manipulation in Egypt span over two decades (Abo-Elwafa *et al*., 1995; El-Farash *et al.,* 1996; Taghian and El-Aref, 1997; Abo-Elwafa, 1999a; Abo-Elwafa 1999b; Abo-Elwafa and Ismail, 1999; El-Helw *et al.,* 1999; Abo-Elwafa and Ahmed, 2001a; Abo-Elwafa and Ahmed, 2001b; El-Helw *et al.,* 2001; El-Helw *et al.,* 2002; Abo-Elwafa and Abo-Salama 2003; Taghian, and Abo-Elwafa 2003; Abdel-Razik 2004; Abo-Elwafa 2004; El-Morshidy *et al* 2004; Abo-Elwafa 2007; Hesham *et al.,*2009; Abo-Elwafa 2011; Fawaz *et al* 2013; Fawaz 2014 and Abo-Elwafa *et al*., 2015). Makinde *et al*. (2009) observed that the debate of biotechnology and sustainable sugar cane production in Nigeria and Northern Africa nations raise several key issues:

(i) How can biotechnological techniques be transferred to Nigeria and Northern African countries to strengthen their competence to acquire, assimilate, further develop, and effectively apply the technology for enhanced sugar cane production?
(ii) What policy and institutional arrangements should be put in place to make the technology and its products accessible to rural sugar cane farmers in Africa?

It must be acknowledged that biotechnology on its own may not be the panacea for the world's problem of the food crisis, sugar cane included. However, genetic engineering presents the outstanding potential to increase the efficiency of both crop improvement and animal production, thereby enhancing global food production and availability in a sustainable way (Ochem, 2003). This is achievable once the entire technology can be integrated into the traditional smallholder farming systems. Sustainable sugar cane production will require that Nigeria and Northern African countries make prudent choices and that they are not restricted to using only the technologies available today. Making such choices require access to a wider range of technologies, especially those resulting from advances in molecular biology. Thus, using the techniques of modern biotechnology, one or two genes may be transferred to a highly developed crop variety to impart a new character that would increase its yield (Asian Development Bank (ADB), 2001)

However, while increases in crop yield are the most obvious applications of modern biotechnology in sugar cane agriculture, it is also the most difficult one. Current genetic engineering techniques work best for effects that are controlled by a single gene (Simonds, 1991). Many of the genetic characteristics associated with yield, such as enhanced growth, are controlled by a large number of genes, each of which has a minimal effect on the overall yield (Bruce and Bruce, 1999). There is, therefore, much scientific work to be done in this area and the need to develop pests and disease resistant sugarcane varieties, more especially with the renewed focus on improved sugarcane breeding. Other areas where biotechnological tools can be employed to improve sustainable sugar cane production are in bio-organic matter, bio-organometal fertiliser, bio fertigation, bio-agrochemicals among others.

BIOTECH-CROPS AND AGROCHEMICALS SYSTEM

Biotechnology is being shaped within the same social context and value system that led to chemical dependence. The same institutions that developed and promoted chemical-style farming, agrochemical giants such as Monsanto, DuPont, and Ciba-Geigy, and the USDA, are now proclaiming biotechnology as the route to sustaining high yields. While reducing the dependence on chemicals and the attendant problems, agrochemical companies are investing millions of dollars in biotechnology research to create genetically engineered plants, animals, and microorganisms to repel pests, make fertilisers, and enhance yield (James, 2008).

In sugar cane production, more efforts had been invested in enhanced yield and pests/diseases resistant variety development. Most of the current commercial applications of modern biotechnology in cane agriculture are on reducing the dependence of farmers on agrochemicals. For example, *Bacillus thuringiensis* (Bt) is a soil bacterium that produces a protein with insecticidal qualities. Traditionally, a fermentation process has been used to produce an insecticidal spray from these bacteria. In this form, the Bt toxin occurs as an inactive protoxin which requires digestion by an insect to be effective. There are several Bt toxins and each one is specific to certain target insects. Crop plants such as tomatoes, potatoes, cotton have now been engineered to contain and express the genes for Bt toxin, which they produce in its active form (James, 2002). Cane scientists are, therefore, challenged to explore similar technological breakthrough in Nigeria and Northern Africa countries as having been the case with the other crops. Also, application of this improved genetic breeding technique to sugar cane will greatly improve the techniques to solve stalk borers and grubs infestations on sugar cane for maximum productivity. It has been reported that when a susceptible insect ingests the transgenic crop cultivar expressing the Bt protein, it stops feeding and soon, thereafter dies as a result of the Bt toxin binding to its gut wall. Bt corn is now commercially available in a number of countries to control corn borer, a lepidopteran insect, which is otherwise controlled by spraying which is a more difficult process (James, 2002, New Scientist, 2008). The technique can be adopted by sugar cane entomologists to combat the menace of sugar cane stalk borers in Nigeria and Northern African countries.

Crops have also been genetically engineered to acquire tolerance to broad-spectrum herbicides.The lack of herbicides with broad-spectrum activity and no crop injury was a consistent limitation in crop weed management. Multiple applications of numerous herbicides were routinely used to control a wide range of weed species detrimental to agronomic crops (New Scientist, 2008). Weed management tended to rely on pre-emergence where herbicide applications were done in response to expected weed infestations rather than in response to actual weeds present (New Scientist, 2008). Mechanical cultivation and hand weeding were often necessary to control weeds not controlled by herbicide applications. The introduction of herbicide-tolerant crops has the potential of reducing the number of herbicide active ingredients used for weed management. Reducing the number of herbicide applications made during a season, and increasing yield due to improved weed management and less crop injury (New Scientist, 2008) improved the quality of crop production as less residual chemicals became bio-accumulated into crop tissues. Transgenic crops that express tolerance to glyphosate, glufosinate and bromoxynil have been developed (Gianessi *et al*., 2002). These herbicides can now be sprayed on transgenic crops without inflicting damage on the crops while killing nearby weeds in sugar cane.

Weeds are known to constitute the greatest problem of sugar cane production in Nigeria and also in Northern African countries (Fadayomi and Abayomi, 1988). For example, weeds compete with sugar cane, for soil nutrients, space, water and light and they also serve as alternative hosts to vertebrate and invertebrate pests and plant pathogens that are harmful to the crop (Zimdahl, 1980; Kolo *et al*., 1999). Weeds also hinder crop harvest and increase the cost of such operations and finally severely reduce crop yield and quality. For example, uncontrolled weed interference in the crop has been reported to cause between 12 and 78% reductions in cane yield depending on weed species, weed density and the sugarcane crop cycle in Nigeria and elsewhere (Fadayomi and Abayomi, 1988). From 1996 to 2001, herbicide tolerance was the most dominant trait introduced to commercially available transgenic crops, followed by insect resistance. In 2001, herbicide tolerance accounted for 77% of the 626,000 square kilometres planted to transgenic crops; Bt crops accounted for 15%; and "stacked genes" for herbicide tolerance and insect resistance used in both cotton and corn accounted for 8% (James, 2002). It is, therefore, possible to develop such biotech sugarcane cultivars that will stack genes for herbicide tolerance and insect resistance as with the three crops mentioned above. Thus, Egypt stands out clearly as the only country in the reported areas that has initiated studies in Biotech crops (Table 1).

Biotechnology and vulnerability of crops to environmental stresses have been reported in many crops and sugar cane and other crops containing genes that will enable them to withstand biotic and abiotic stresses may be developed (Ochem, 2003, Chondler and Dunwell, 2008). For example, drought, and excessively salty soil are two important limiting factors in sugar cane and crop productivity as a whole. Biotechnologists are studying plants that can cope with

Table 1. The global area of biotech crops in 2007 and 2008: By country (million hectares).

Country	2007	%	2008	%	+/-	% Increase
USA*	57.7	50	62.5	50	+4.8	+8
Argentina*	19.1	17	21.0	17	+1.9	+10
Brazil*	15.0	13	15.8	13	+0.8	+5
India*	6.2	5	7.6	6	+1.4	+23
Canada*	7.0	6	7.6	6	+0.6	+9
China*	3.8	3	3.8	3	+0.0	--
Paraguay*	2.6	2	2.7	2	+0.1	+4
South Africa*	1.8	2	1.8	1	+0.0	--
Uruguay*	0.5	<1	0.7	1	+0.2	+40
Bolivia*	--	--	0.6	<1	+0.6	--
Philippines*	0.3	<1	0.4	<1	+0.1	+33
Australia*	0.1	<1	0.2	<1	+0.1	+100
Mixico*	0.1	<1	0.1	<1	<0.1	--
Spain*	0.1	<1	0.1	<1	<0.1	--
Chile	<0.1	<1	<1	<1	<0.1	--
Colombia	<0.1	<1	<1	<1	<0.1	--
Honduras	<0.1	<1	<1	<1	<0.1	--
Burkina Faso	<0.1	<1	<1	<1	<0.1	--
Czech Republic	<0.1	<1	<1	<1	<0.1	--
Romania	<0.1	<1	<1	<1	<0.1	
Portugal	<0.1	<1	<1	<1	<0.1	--
Germany	<0.1	<1	<1	<1	<0.1	--
Poland	<0.1	<1	<1	<1	<0.1	--
Slovakia	<0.1	<1	<1	<1	<0.1	--
Egypt	--	--	<1	<1	<0.1	
Total	114.3	100	125.0	100	+10.7	+9.4

*Mega-biotech countries (14) growing 50,000 hectares, or more, of biotech crops.Source: Clive James, 2008.

these extreme conditions with the hope of finding the genes that enable them to do so and eventually transferring these genes to the more desirable crops. One of the latest developments is the identification of a plant gene, from *Arabidopsis thaliana*, a tiny weed that is often used for plant research because it is very easy to grow and its genetic code is well mapped out (Sara, 1999). When this gene was inserted into tomato and tobacco cells, the cells were able to withstand environmental stresses like salt, drought, cold and heat, far more than ordinary cells. If these preliminary results prove successful in larger trials, then At-DBF2 genes can help in engineering crops such as sugar cane that can better withstand harsh environments (Sara, 1999).

Biotechnology could make significant contributions to sustainable sugarcane production systems, but those contributions would have more to do with enhanced understanding and manipulation of crops-pests-environment interactions. Thus, if the molecular and biochemical steps in disease development are characterised in sugar cane, scientists can determine not only which steps are susceptible to control measures, but what measures will be successful in interrupting disease (s) development. This could lead to developing specific and targeted strategies to block critical interactions and prevent several sugar cane and other crops diseases. These strategies may employ natural disease suppressive agents in crops interplant or rotation, incorporate specific genes for disease/pest resistance, enhance natural defence mechanisms, or involve altered cultural conditions and planting dates (Kimbrell, 2002).

HERBICIDE-TOLERANT CROPS

Genetically engineered herbicide-tolerant crops are likely to be the first commercially available products. They are engineered to contain new genes that help plants avoid the harmful effects of particular weed killers (New Scientist, 2008). Currently, a crop's sensitivity to a weed killer limits the amount of herbicide, growers can apply. With herbicide-tolerant crops, farmers can be persuaded to use more of a particular herbicide to kill weeds without damaging their crop. Herbicide-tolerant crops represent a simple strategy for chemical companies to market more of their herbicides. Thus, Monsanto, for example, has already field-tested genetically engineered glyphosate-tolerant tomato, cotton, soyabean, flax, and canola. Rather than directing agriculture from its dependence on toxic chemicals, herbicide-tolerant crops tend to perpetuate and extend the chemical pesticide era and its attendant human health and environmental toll. Studies linked various weed killers with cancer, nervous disorders, behavioural changes, and skin diseases in humans and animals (USEPA, 2006). In addition to poisoning farm workers who handled herbicides, weed killers enter groundwater and other drinking water supplies, contaminate food, and destroy wildlife and their habitats (USEPA, 2006). Not only do herbicide-tolerant crops sustain dependence on harmful chemicals, they also have the potential, in the long run, to exacerbate weed control problems (New Scientist, 2008).

Widespread use of these crops and their associated herbicides will exert significant pressure on populations of weeds to develop tolerance to the herbicides, thus rendering them ineffective in controlling the weeds. Already, herbicide-resistant weeds have arisen in areas where certain weed killers were heavily used (Kimbrell, 2002). The larger amounts of particular herbicides applied in association with herbicide-tolerant crops will only increase the selection pressure for additional resistant weeds. Furthermore, the transfer of genes for herbicide resistance to weedy relatives could make some weeds more difficult to control in sugar cane fields (Kimbrell, 2002). For example, oilseed crucifers (rapeseed or canola) that have been engineered to resist herbicides are related to wild mustards that are important weeds in U.S agriculture. It is virtually certain that herbicide-tolerant genes would be transferred via cross pollination from the engineered crucifers to wild, weedy relatives, resulting in weeds resistant to herbicides and therefore making them more difficult to control (Kimbrell, 2002).

In spite of all these seemingly negative effects of herbicide-tolerant crops, sugar cane scientists in Nigeria and Northern African countries should be encouraged to explore the development of herbicide-tolerant sugar cane to reduce the weeding regimes in cane agriculture being witnessed in these areas at present (Fadayomi and Abayomi, 1988).

GENETICALLY MODIFIED ORGANISMS (GMOS) AND SUGARCANE PRODUCTION

Genetically Modified Organisms (GMOs) are organisms whose genetic materials have been altered by genetic engineering techniques generally known as recombinant DNA technology. It has been canvassed that the use of the word “biotech” is a better phrase than the original Genetically Modified Organisms to imply that the science of biotechnology has simply been used to incorporate genetic changes within a plant instead of the genetic changes made through traditional breeding methods (Richard, 2009b). In line with this, genomic and molecular cytogenetic data have provided strong evidence that *Saccharum barberi* and *S. sinense* were derived from interspecific hybridization between *S. officinarum* and *S. spontaneum* (D’Hont *et al*., 2002). *Saccharum robustum* and *S. spontaneum* are two wild species with different basic chromosomes, x = 10 and x = 8, respectively ((D’Hont *et al.,* 1995; 1996; 1998; Ha *et al*., 1999). These two wild species have a wide range of chromosome numbers and ploidy levels with 2n = 60 - 170 for *S. robustum* and 2n = 40 - 128 for *S. spontaneum* (Irvine, 1999). *Saccharum robustum* has been postulated to be the progenitor of the high sugar content species, *S. officinarum*. The unique basic chromosome number and distinctive DNA fingerprints of *S. spontaneum* from the other species of *Saccharum* are the reasons for a proposal to divide this genus to only two species, *S. spontaneum* as traditionally defined and *S. officinarum* including all other species and interspecific hybrids (Irvine, 1999).

Dutch breeders in early 1900 utilized this unusual phenomenon in sugar cane improvement to integrate resistance genes for biotic and abiotic stresses from the wild species *S. spontaneum* and quickly recovered the high sugar content property by a few backcrosses to the high sugar content species *S. officinarum*. For that reason, all current sugar cane cultivars in production are hybrids with 80-90% of the genome from *S. officinarum* and 10-20% of the genome from *S. spontaneum* (Grivet *et al*., 1996; Hoarau *et al*., 2002).

The complexity of the autopolyploid genome and the interspecific hybridization of modern cultivars hindered progress in genetic/genomic research and the application of genomic tools in sugar cane breeding programmes. Thus, the only sugar cane bacterial artificial chromosome (BAC) library that we are aware of was constructed from the hybrid cultivar R570 with 2n = 115 chromosomes. Given an estimated genome size of 10 Gb, this BAC library provided 1.3× coverage of the polyploid genome and 14× coverage of the basic chromosome set (Tomkins *et al*., 1999; D’Hont, 2005). Similar studies are needed by scientists in Nigeria and Northern African countries for cane improvement and production.

Sugar cane cultivars used for genetic mapping often have more than 100 chromosomes, and all sugar cane genetic maps constructed to date appear to be incomplete, due to the large number of chromosomes to be mapped and the limited genomic sequences available for developing markers (Hoarau *et al*., 2002; Ming *et al*., 1998; 2005; Aitken *et al*., 2005; Garcia *et al*., 2006). This deficiency has restricted the application of marker-assisted selection because much of the genome cannot yet be scanned for target traits. However, sugar cane is in the forefront as a source of biofuel, and this has stimulated investment from both private and public sectors in sugarcane research. Coupled with the decreased cost of DNA sequencing using the next generation sequencing technologies, the once daunting and prohibitive task of sequencing the autopolyploid sugarcane genome becomes a real possibility (Wang *et al*., 2010). This possibility has to be exploited by cane researchers in Nigeria and Northern African countries to have cane productivity through biotechnological means, in spite of the fact that sugar cane's large polyploid genome coupled with interspecific hybridization and aneuploid hinder sugarcane genomic studies (Wang *et al*., 2010).

INSECT RESISTANCE BIO-TECH CROPS

Reducing sugar cane crop loss caused by insects is also a major focus of agricultural biotechnology research. Sandoz Crop Protection and Crop Genetics International are genetically engineering microorganisms containing Bt toxin to act as biocontrol agents. Bt is a soil microorganism that has been used for twenty years as a commercial biocontrol agent against certain insect pests (New Scientist, 2008). The GMO crops protect plants from damage by insects; examples of such crops include Starlink and cotton, which accounts for 63% of US cotton acreage.

Knowing that specific toxins were responsible for Bt's insecticidal activity, genetic engineers have isolated and removed the genes that produce the toxins, and placed them in plants and microorganisms (New Scientist, 2008). Despite their promise for reducing the use of chemical insecticides, widespread use of Bt-containing crops and microbes poses a potentially significant problem to accelerated evolution of pest resistance to Bt. If this were to happen, cane agriculture would lose one of its safest, most valuable bio-control agents. Current genetic engineering techniques work best for effects that are controlled by a single gene. Many of the genetic characteristics associated with yield, such as enhanced growth, and sugar cane crop itself are controlled by a large number of genes, each of which has a minimal effect on the overall yield. Already, some insect populations like diamondback moth have become resistant to the Bt toxin after prolonged exposure (Kimbrell, 2002). Resistance in a particular insect pest population means that Bt would no longer be effective in controlling that pest. It is generally accepted that the intensive use of Bt in genetically engineered organisms will accelerate the selection pressure on insect populations to develop resistance. Thus, there were beliefs that similar or better pest-resistance traits can be acquired through traditional breeding practices, and resistance to various pests can be gained through hybridization or cross-pollination with wild species. In some cases, wild species are the primary source of resistance traits; for example, some tomato cultivars that have gained resistance to at least nineteen diseases did so through crossing with wild populations of tomatoes (Kimbrell, 2002).

Sugar cane scientists are very familiar with crossing sugarcane cultivars with their wild relatives like Erianthus. Thus sugar cane can be engineered with such wild relatives that produce the Bt toxin throughout their life, insects will be exposed to them more frequently and for longer periods (Chondler and Dunwell, 2008). This intensified selection pressure contrasts with conventional methods of delivering Bt where the toxin is active for only a limited period after application.

There is also concern that GMOs will cross-pollinate with wild species and permanently alternative populations' genetic integrity as there are already identified populations of wild plants with transgenic genes.

The GMO gene's flow to related weed species has become a source of concern, as well as the cross-pollination with non-transgenic crops. Since many GMO crops are harvested for their seed, seed spillage constitutes a great problem to volunteer plants in rotated fields, as well as seed-spillage during transportation in other crops (Chondler and Dunwell, 2008). This area of research should interest sugarcane breeders in Nigeria and other Northern African countries in exploiting for the benefit of sugar cane growers.

Concerns like these gave birth to the Africa Biosafety Model Law and all the five regions of Africa have specific standards set for them to ensure the safety of Bt crops including sugar cane. In Nigeria, the foundation of sugar cane biotechnology is being started at the National Cereals Research Institute, (NCRI) Badeggi, the institute charged with the mandate of genetic improvement of sugarcane, with the erection and furnishing of tissue culture laboratory for rapid seed cane multiplication studies.

In Northern African countries, Egypt stands out as the most developed biotech country in cane agriculture (Baksha *et al*., 2002; El-Geddawy *et al*., 2008; El-Farash, *et al* (1996); Taghian and El-Aref (1997); El-Helw *et al*., (1999); El-Helw *et al*., (2001), El-Helw *et al*., (2002); Abo-Elwafa and Abo-Salama (2003); Abdel-Razik (2004); Abo-Elwafa (2004); Abo-Elwafa (2007); El-Seehy *et al*., (2008); Abo-Elwafa (2011); Fawaz *et al.,* (2013); Fawaz (2014) and Abo-Elwafa *et al.,* 2015).

SUGAR CANE PRODUCTION AND ENVIRONMENTAL POLLUTION

Biotechnology is being used to engineer and adapt organisms especially microorganisms in an effort to finding sustainable ways to clean up contaminated environments.

The elimination of a wide range of pollutants and wastes from the environment is an absolute requirement to promote a sustainable development of our society with low environmental impact.

Sugar cane production and its products such as sugar and ethanol as well as its by-products like bagasse, filter mud and other waste products if not efficiently used with biotechnological techniques could create environmental pollution problems (Heffner *et al*., 2009).

Consequently, biological processes play a major role in the removal of contaminants and biotechnology is taking advantage of the astonishing catabolic versatility of microorganisms to degrade or convert such compounds. New methodological breakthroughs in sequencing, proteomics, bioinformatics, and imaging are producing vast amounts of information (Heffner *et al*., 2009). In the field of Environmental Microbiology, genome-based global studies open a new era providing unprecedented *in silico* views of metabolic and regulatory networks, as well as clues to the evolution of degradation pathways and to the molecular adaptation strategies to changing environmental conditions. Thus, functional genomics and metagenomic approaches are increasing our understanding of the relative importance of different pathways and regulatory networks to carbon flux in particular environments and for particular compounds as they will certainly accelerate the development of bioremediation technologies and biotransformation processes (Heffner *et al*., 2009), where sugar cane by-products could constitute environmental problems.

Advances in biotechnology in sugar cane utilisation

The world's sugar cane industry is much larger and takes in many of the world's large agricultural countries. While assessing several biotech projects throughout the world in sugar crops, the sugar cane industry is not as well advanced as the beet industry (Gianessi *et al*., 2002, El-Geddawy *et al*., 2008). Several countries are moving forward and speaking, as is the case with other well developed biotech countries like Bangladesh and or Egypt (Baksha *et al*., 2002) about potential commercialization within the next few years, Brazil and Australia are the two leading countries in biotech issues. Several other countries are working to move biotech forward and have experimental material planted in secure locations while other industries are still working toward biotech within the laboratory or are at least interested in pursuing the use of biotechnology.

For Africa generally, in order to address the issue of inadequate resources to develop and safely apply biotechnology for human, infrastructure and funding, the African Union (AU) through the NEPAD Office of Science and Technology established the African Biosciences Initiative in 2005. This led to the creation of networks of centres of excellence in strategically placed hubs around the continent, viz, BecANet in Kenya, SANBio in South Africa, WABNet in Senegal, and NABNet in Egypt; with these hubs are a number of nodes. Each of the five AU regions has the following biotechnology missions to carry out as indicated in (Table 2).

Biotechnology research has led plant breeders to develop more efficient systems for selection of outstanding sugarcane germplasm. It is an indirect selection process where a trait of interest is selected not based on the trait itself but on a marker linked to it.

In sugar cane, much work has been done on molecular markers associated with agronomic characters and biotechnology has achieved the development and utilisation of molecular diagnosis for pathogens (Pan *et al*., 2008, El-Seehy *et al*., (2008), Abd El-Tawab *et al*., 2008).

Because yield losses are extremely important to sugar cane industry, the use of enzyme-linked antibodies for serological detection of plant pathogens as well as enzyme-linked immunosorbent assays have been very important in plant diseases diagnosis (Richard, 2009a).

It has also been reported that through biotechnological tools, valuable pharmaceuticals, amino acids and other saleable products could be produced using sugar cane as a carrier. At present, sugarcane is important not only for the production of sweeteners but also for energy (Richard, 2009b). It is anticipated that this usage will increase in future and the use of biotechnology will greatly enhance the utilisation of sugar cane. There are numerous other aspects of biotech that are very important to sugar cane industry that can normally be utilised without any or much expenses for commercialization as experienced with varieties genetically modified through biotech.

Makinde *et al*. (2009) reported that for biotechnological researchers to operate effectively there should be political will and commitment to using the tools. There is need to have adequate resources, human and infrastructure and capacity building/strengthening among Nigerian and Northern Africa countries in order to enforce synergy for biotechnological successes in sugar and bioenergy production.

In this regard, regulatory frameworks that will work and are enforceable have been established by the AU through the NEPAD Office of Science and Technology (Table 3).

For these frameworks to be functional and effective all stakeholders' are to be involved. The need to promote intra-Africa trade through harmonisation of biosafety regulation as the result of porous borders and removal of trade barriers among the traditional trading partners is also stressed. The regulatory frameworks again assumed enhancement of public understanding and acceptance of the products of the technology (Makinde *et al*., 2009).

Conclusion

The application of molecular breeding techniques in

Table 2. NEPAD OST networks of centres of excellence in biosciences.

Networks	Nodal point	Hub national	Centre focus	Area of work
NABNet (North African Biosciences Network)	Egypt	Research Centre (NRC)	BioPharma-ceuticals	North Africa: to lead the continent in research into biopharmaceuticals, drug manufacturing and test kits.
WABNet (West African Biosciences Network)	Senegal	Senegalese Institute of Agricultural Research (ISRA)	Crop Biotech	West Africa: to carry out research using biotechnology tools to develop cash crops, cereals, grain legumes, fruits. Vegetables and root/tuber crops.
SANBio (Southern African Network for Biosciences	South Africa	CSIR, Bioscience Unit	Health Biotech	Southern Africa: to deliver benefits from health biotechnology by researching into the causes and prevention methods of a range of diseases, in particular, TB, malaria and HIV/AIDS.
BecANet (Biosciences East and Central African)	Kenya	International Livestock Research Institute (ILRI)	Animal Biotech	East Africa: to focus on research into livestock pests and diseases in order to improve animal health and husbandry. Central Africa: to build and strengthen indigenous capacity by identifying, conserving and sustainably using natural resources and also researching into the impact on biodiversity of events such as climate change and natural disasters.

Adapted from Makinde *et al.*, 2009.

Table 3. Status of the member states with regard to the development of their national biosafety frameworks, as of June 2009.

Function NBFs	Algeria, Egypt, Sudan, Burkina Faso, Mali, Mauritius, Kenya, Zimbabwe, South Africa, Togo and Tunisia	11
Interim NBFS	Senegal, Ghana, Nigeria, Namibia, Zambia, Tanzania, Mozambique, Ethiopia, Uganda, Madagascar, Rwanda and Malawi	12
Work in Progress	Botswana, Burundi, DR Congo, Congo, Gabon, Cameroon Central African Republic, Benin, Ivory Coast, Sierra Leone, Liberia, Guinea Bissau, Mauritania, Niger, Libya, Eritrea, Djibouti, Burundi, Swaziland, Lesotho, Guinea, Gambia, Madagascar and Seychelles	24
No Action Yet	Angola, Somalia, Equatorial Guinea, Chad, Guinea Bissau, Western Sahara and Morocco	7

Adapted from Makinde *et al.*, 2009.

sugar cane has the potential to overcome constraints of diseases and other biotic factors by introducing varieties that have yield outputs which are above the average of the standard or candidate varieties. A replacement of the high input demand of pesticides and agrochemicals for sugarcane in the region with variants from biotechnology procedure will reduce environmental degradation and promote global best practices in sugarcane cultivation in the sugar industry in Nigeria and Northern African countries. The Biosafety Law is very much in place in Nigeria and other countries of the African region and is an inspiration to scientists and the industry to respond to. A coordination of the research initiatives can take into consideration the individual country Biosafety laws. A group coordinated research network on sugar cane biotechnology is advocated for; where institutional roles and responsibilities can be defined with the involvement of all the key ministries, institutions and the private sector

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REFERENCES

Abah J, Wada AC, Ishaq MN (2010). The Role of Biotechnology in Ensuring Food Security and Sustainable Agriculture. *AJB* 9 (26). www.academicjournals.org/AJB.

Abdel-Razik RM (2004). "Genetically *studies on sugarcane plants derived from* in vitro *culture". M.Sc. Thesis, High Institute for Sugar technology, Assiut Univ., Egypt, 2004.*

Abd El-Tawab FM, Fahmy EM, Allam AI, Khttab SA, Abdel Fatah AI, Elsayed OE, Shoaib RM (2008). Development of Molecular Markers Assisted with Smut Resistance in Sugar cane. Pp 415-422 In: *Meeting the challenges of Sugar Crops and Integrated Industries in Developing countries*, Al Arish, Egypt.

Abo-Elwafa A (1999a). Response of immature embryos *in vitro* regeneration of some wheat (*T.aestivum*) genotypes under different osmotic stress of mannitol . *Assiut J. Agric. Sci*., 30 (3): 25:34 *Activities (MUCIA),USA*

Abo-Elwafa A (1999b). Response of immature embryos of wheat genotypes *in vitro* regeneration under different NACL concentrations. *Assiut J. Agric. Sci*., 30 (3): 35-46.

Abo-Elwafa A (2004).In field assessment of somaclonal variability in sugarcane through callus culture. *Assiut J. Agric. Sci*., 35(4): 29-47.

Abo-Elwafa A (2007). Sugarcane *In vitro* culture. *In*; A short course on plant tissue culture and transformation. *In a collaboration between Engineering & Tissue Culture Unit, Genetic Engineering & Molecular Biology Research Centre, Assiut University and Midwest Universities Consortium for International*. Assiut, Egypt.11-15 March 2007, Pp; 33-39.

Abo-Elwafa A (2011). In field assessment of somaclonal variation among sugarcane clones derived through immature leaf callus culture. *Egyptian Sugar J.* Vol. 4: 1-19.

Abo-Elwafa A, Murai K, Shimada T (1995). Intra and inter-specific variations in *Lens* revealed by RAPD markers. *Theor.Appl.Genet.* 90: 335-340.

Abo-Elwafa, Ismail AA. (1999).Callus induction and plant regeneration from a culture of immature embryos of spring wheat. *Assiut J. Agric. Sci*., 30(3): 13-23

Abo-Elwafa A, Abo-Salama AM (2003). A study of somaclonal induced phenotypic variability in sugarcane. International Conf., on The Arab Region and Africa in the World Sugar Context March, 9-12, Aswan, Egypt, P.6/1:16.

Abo-Elwafa A, Ahmed TA (2001a). Somaclonal variation: an attractive source of variability for crop improvement. The second Pl. Breed. Conf., October 2, Assiut University, Assiut, Egypt. pp. 459-471.

Abo-Elwafa A, Ahmed TA (2001b). Applications of Molecular markers in crop improvement. The second Pl. Breed. Conf., October 2, Assiut University, Assiut, Egypt, pp. 473-494.

Abo-Elwafa A, Hamada A, Nosaer H, Faheim H (2015). Assessment of somaclonal variation, correlation and stepwise regression to evaluate new sugarcane somaclones. *Egyptian Sugar. J.* 8:139-158.

Aitken KS, Jackson PA, McIntyre CL (2005). A combination of AFLP and SSR markers provides extensive map coverage and identification of homo(no)logous linkage groups in a sugarcane cultivar. *Theor Appl Genet 2005*, 110(5):789-801.

Asian Development Bank (ADB) (2001). Asian Development Bank, Agricultural Biotechnology, Poverty Reduction and Food Security. Manila. Also available from ADB.org

Baksha R, Alam R, Karim MZ, Paul SK, Hossain MA, Miah MAS, Rahman ABMM (2002). *In vitro* shoot tip Culture of Sugar cane (*Saccharum officinarum*) Variety lid 28. *Biotechnology*, Vol. 1: No 2-4:67-72

Bruce D, Bruce A (1999). Engineering Genesis: The Ethics of Genetic Engineering, London: Earthscan Publications. ISBN 1853835706.

Chondler S, Dunwell JM (2008). Gene Flow, Risk Assessment and the Environmental Release of Transgenic Plants. *Critical Reviews in Plant Science*. 27: 25-49.

D'Hont A (2005). Unravelling the genome structure of polyploids using FISH and GISH; examples of sugarcane and banana. *Cytogenet Genome Res.* 109(1-3):27-33.

D'Hont A, Paulet F, Glaszmann JC (2002). Oligoclonal interspecific origin of 'North Indian' and 'Chinese' sugar canes. *Chromosome Res*. 10(3):253-262.

D'Hont A, Grivet L, Feldmann P, Rao PS, Berding N, Glaszmann JC (1995). Identification and characterization of sugarcane intergeneric hybrids, *Saccharum officinarum* x *Erianthus arundinaceous*, with molecular markers and DNA *In situ* hybridization. *Theor Appl Genet.* 91:320-326.

D'Hont A, Grivet L, Feldmann P, Rao S, Berding N, Glaszmann JC (1996).Characterization of the double genome structure of modern sugarcane cultivars (*Saccharum spp.*) by molecular cytogenetics. *Mol Gen Genet.* 250(4):405-413.

D'Hont A, Ison D, Alix K, Roux C, Glaszmann JC (1998). Determination of basic chromosome numbers in the genus Saccharum by physical mapping of ribosomal RNA genes. *Genome.* 41:221-225.

El-Farash EM, El-Aref HM, Fahmy FG (1996). Exploring the genotypic potential of selected sugarcane somaclonal for improved sugar content and yield. *Assiut J. Agric. Sci*.,27(2): 225-238.

El-Geddawy DIH, Azzam CR, Khalil M (2008). Somaclonal variation in sugar cane through tissue culture and subsequent screening for molecular polymorphisms. Pp.307-320. In: *Meeting the challenges of Sugar Crops and Integrated Industries in Developing Countries*, Al Arish, Egypt.

El-Helw MR, El-Aref HM, Taghian AS (1999). Establishment of anther culture technique in sugarcane. First International Conference On Sugar and Integrated Industries"Present and Future", Luxor, Egypt February 15-18.

El-Helw MR, El-Aref HM, Taghian AS (2001). Improving cane yield, salinity tolerance and disease resistance using anther and tissue culture techniques in sugar cane. The 2nd International Conference On: Sugar and Integrated industries "The Role of the Arab Region in the World Sugar Economy", Luxor, Egypt February 18-21, pp. 119-130.

El-Helw MR, El-Aref HM, Taghian AS (2002). The role of genetic and non-genetic factors in plant regeneration from immature inflorescence of sugarcane and evaluation of regenerants. *Assiut J. Agric. Sci*., 33:23-46.

El-Morshidy MA, Abo-Elwafa A, Allam AY (2004). Assessment of some new wheat lines variability using RAPD and protein patterns. *Assiut J. Agric. Sci*., 35(1): 221-249.

El-Seehy SO, Badawy M, Attallah S, Yaseen R (2008). Genetic biomarkers and resistance of sugar cane mosaic virus. Pp. 355 – 361. In: *Meeting the challenges of Sugar Crops and Integrated Industries in Developing countries,* Al Arish, Egypt.

Fadayomi O, Abayomi YA (1988). Effects of varying periods of weed interference on Sugarcane (*Saccharum officinarum* L), growth and yield. *Nigerian Journal of Weed Science*. 1: 65.

Fawaz AW (2014). "*Molecular Biological Studies on Sugarcane*". PhD thesis, Genetic Engineering and Biotechnology Research Institute, University of Sadat City., Egypt.

Fawaz AW, Nasr MI, Hamdy M, El-Aref Hemeida AA, Alaa Abouel-Khier SM (2013). Genetic Analysis and Expected Response to Selection for Some Agronomical and Juice Quality Traits in Sugarcane (*Saccharum officinarum* L.). *Assiut J. Agric. Sci.* 44(3): 63-67.

Garcia AA, Kido EA, Meza AN, Souza HM, Pinto LRMM, Pastina CS, Leite JA, Silva EC, Ulian, A, Figueira Raud Souza AP (2006). Development of an integrated genetic map of a sugarcane (*Saccharum spp*.) commercial cross, based on a maximum-likelihood approach for estimation of linkage and linkage phases. *Theor Appl Genet*. 112(2):298-314.

Gianessi LP, Silvers CS, Sankula S, Carpenter JE (2002). Plant Biotechnology:D.C. National Center for Food and Agricultural Policy.Pp.5–6.

Grivet L, D'Hont A, Roques D, Feldmann P, Lanaud C, Glaszmann JC (1996). RFLP Mapping in Cultivated Sugarcane (*Saccharum spp*.): Genome Organization in a Highly Polyploid and Aneuploid Interspecific Hybrid. *Genetics.* 142:987-1000.

Ha S, Moore PH, Heinz D, Kato S, Ohmido N, Fukui K (1999). Quantitative chromosome map of the polyploid *Saccharum spontaneum* by multicolor fluorescence *In situ* hybridization and imaging methods. *Plant Mol Biol*. 39(6):1165-1173.

Heffner EL, Sorrells ME, Jannink JL(2009). Genomic selection for crop improvement. *Crop Sci.* 49:1-12.

Hesham A, Abo-Elwafa A, Moamed E (2009). Isolation and molecular characterization of catabolic genes related to phenanthrene-degrading bacteria. 1st international conference on biotechnology (Towards Knowledge Based-economy); Feb. 16-18, Center of excellence in biotechnology research, Kin Fahad Cultural Center, Riyadh, Saudi Arabia.

Hoarau JY, Grivet L, Offmann B, Raboin LM, Diorflar JP, Payet J, Hellmann M, D'Hont A, Glaszmann JC (2002). Genetic dissection of a modern sugarcane cultivar (*Saccharum spp*.): II. Detection of QTLs for yield components. *Theor. Appl .Genet*. 105(6-7):1027-1037.

ILO (2009). International Labour Organisation. Key Indicators of the Market.

Irvine JE (1999). *Saccharum species* as horticultural classes. *Theor. Appl. Genet*. 98:186-194.

James C (2002). Global Review of Commercialised Transgenic Crops: 2002. *ISAAA Brief*.

No. 27-2002, at 11–12. Also available from ISAAA.org.

James C (2008). Global Status of Commercialised Biotech/GM Crops: Brief 39 Global Status of Commercialised Biotech/GM Crops.

Kimbrell A (2002). Fatal Harvest: The Tragedy of Industrial Agriculture, Island Press, Washington.

Kingsbury N (2009). Hybrids. The History and Science of Plant Breeding. University of Chicago Press. Chicago.

Kolo IN, Adesiyun AA, Misari SM, Busari LD, Ndarubu AA(1999). Weed as alternative hosts of chewing Sugarcane stem borers. *Nigerian Journal of Plant Protection*. 18: 56-66.

Makinde D, Mumba L, Ambali A (2009). Status of Biotechnology in Africa: Challenges and Opportunities *Asian Biotechnology and Development Review* 11 (3):1-10.

Ming R, Liu SC, Lin YR, Silva J, Wilson W, Braga D, van-Deynze A, Wenslaff TF,Wu KK, Mosore PH, Burnquist W, Sorrells ME, Irvine JE, Paterson AH (1998). Detailed alignment of Saccharum and sorghum chromosomes: comparative organization of closely related diploid and polyploid genomes. *Genetics*. 150(4):1663-1682.

Ming R, Moore PH, Wu KK, D'Hont A, Glaszmann JC, Tew TL, Mirkov TE, Silva J, Jifon J, Rai M, Schnell RJ, Brumbley SM, Lakshmanan P, Comstock JC, Paterson AH (2005). Sugarcane improvement through breeding and biotechnology. *Plant Breeding Review*. 27:15-118.

New Scientist (2008). Genetically Engineered Crops in the U.S: Extent of Adoption.

Ochem AE (2003). Dissemination of Plant Biotechnology - An African Perspective WIPO-UPOV Symposium on Intellectual Property Rights in Plant Biotechnology, Organized by the World Intellectual Property Organization (WIPO) and the International Union for the Protection of New Varieties of Plants (UPOV), Geneva, October 24, 2003.

Pan YB, Scheffler BE, Richard EP Jr (2008). High throughput genotyping of sugarcane clones with microsatellites (SSR) markers. Pp266–272. In: *Meeting the challenges of Sugar Crops and Integrated Industries in Developing Countrie*s, Al Arish, Egypt.

Richard C (2009a). A Simple Description of the Long Term Potential for Biotechnology in Sugar Crops. *S J Sugar Journal* 6-9, Feb. 2009:

Richard, H. (2009b). Agriculture's Sustainable Future: Breeding Better Crops.www.scienceamerica.com/article

Sara, A. (1999). "Drought stress". Nature News.

of Cr Simmonds N.W. 1991. *Genetics of Horizontal Resistance to Diseases ops. Biol. Rev.* 66:189-241.

Taghian AS, Abo-Elwafa A (2003). Multivariate and RAPD analyses of drought tolerance in spring wheat (*Triticum aestivum* L.) *Assiut J. Agric. Sci*., 34(5): 1-25.

Taghian AS, El-Aref HM (1997). Somaclonal variation and differential gene expression of albino and green sugarcane plants. Proceeding of The First Scientific Conf. of Agriculture Sciences, Fac. of Agric., Assiut Univ., Assiut, Egypt December 13-14, Vol. 1:273-286.

Thieman WJ, Palladino MA (2008). Introduction to Biotechnology. Pearson/Benjamin Cummings ISBN 0321491459.

Tomkins JP, Yu Y, Miller-Smith H, Frisch DA, Woo SS, Wing R (1999). A bacterial artificial chromosome library for sugarcane. *Theor Appl Genet.* 99:419-424.

UN (1992). United Nations. The Convention on Biological Diversity. Article 2.

USEPA (2006). Human Health Issues/Pesticides.

Wang J, Roe B, Macmil S, Yu Q, Murray JE, Tang W, Chen C, Najar F, Wiley G, Bowers J, Sluys MAV, Rokhsar DS, Hudson ME, Moose SP, Paterson A, Ming R (2010). Micro collinearity between anti polyploid sugarcane and diploid sorghum genomes. *BMC Genomics*11/261.

Zimdahl RL (1980). Weed-crop competition A Review: International Plant Production Center, Oregon State University, Corvalis.