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Case studies on the use of biotechnologies and on biosafety provisions in four African countries

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ABSTRACT

This review is based on a study commissioned by the European Commission on the evaluation of scientific, technical and institutional challenges, priorities and bottlenecks for biotechnologies and regional harmonisation of biosafety in Africa. Biotechnology was considered within four domains: agricultural biotechnologies ('Green'), industrial biotechnologies and biotechnologies for environmental remediation ('White'), biotechnologies in aquaculture ('Blue') and biotechnologies for healthcare ('Red'). An important consideration was the decline in partnerships between the EU and developing countries because of the original public antipathy to some green biotechnologies, particularly genetically modified organisms (GMOs) and food from GM crops in Europe. The study focus reported here was West Africa (Ghana, Senegal, Mali and Burkina Faso).

The overall conclusion was that whereas high-quality research was proceeding in the countries visited, funding is not sustained and there is little evidence of practical application of biotechnology and benefit to farmers and the wider community. Research and development that was being carried out on genetically modified crop varieties was concentrating on improving food security and therefore unlikely to have significant impact on EU markets and consumers. However, there is much non-controversial green biotechnology such as molecular diagnostics for plant and animal disease and marker-assisted selection for breeding that has great potential application. Regarding white biotechnology, it is currently occupying only a very small industrial niche in West Africa, basically in the sole sector of the production of liquid biofuels (i.e., bio-ethanol) from indigenous and locally planted biomass (very often non-food crops). The presence of diffused small-scale fish production is the basis to develop and apply new (Blue) aquaculture technologies and, where the research conditions and the production sector can permit, to increase this type of production and the economy of this depressed areas. However, the problems bound to environmental protection must not be forgotten; priority should be given to monitor the risks of introduction of foreign species. Red biotechnologies potentially bring a vast domain of powerful tools and processes to achieve better human health, most notably improved diagnostics by molecular techniques, better targeting of pathogens and a better knowledge of their sensitivities to drugs to permit better treatment.

Abbreviations: AATF, Africa Agriculture Technology Foundation; ABNE, African Biosafety Network of Expertise (NEPAD); AIDCO, Europe Aid Co-operation Office; ASARECA, Association for Strengthening Agricultural Research in Eastern & Southern Africa; BECANet, Biotechnology for Eastern and Central Africa; Bt, *Bacillus thuringiensis*; CILSS, Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel; CORAF/WECARD, West and Central African Consortium for Agricultural Research and Development; CRODT, Centre de Recherches Océanographiques Dakar-Thiaroye; DFID, Department for International Development (UK); ECART-EEIG, European Consortium for Agricultural Research in the Tropics-European Economic Interest Grouping (now AGRINATURA); ECOWAS/CEDEAO, Economic Community of West African States; ELISA, enzyme-linked immunosorbent assay; EDCTP, European & Developing Countries Clinical Trials Partnership; FARA, Forum for Agricultural Research in Africa; GIFT, genetic improvement of farmed tilapia; GMO, genetically modified organism; IPR, intellectual property rights; IRD, Institut de Recherche pour le Développement (France); NABNet, North African Biotechnology Network; NEPAD, New Partnership for African Development; NGO, non-governmental organisation; R&D, research and development; RTD, research and technical development; SABNet, Southern African Biotechnology Network; SCARDA, Strengthening Capacity for Agricultural Research and Development in Africa; TRIPS, (Agreement on) Trade-Related Intellectual Property Rights (WTO); UEMOA, West African Economic and Monetary Union; USAID, United States Agency for International Development.

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Biosafety regulatory frameworks had been initiated in several countries, starting with primary biosafety law. However, disparate attitudes to the purpose of biosafety regulation (e.g., fostering informed decision-making versus 'giving the green-light for a flood of GMOs') currently prevent a needed consensus for sub-regional harmonisation. To date, most R&D funding has come from North America with some commercial interests from Asia, but African biotechnology workers expressed strong desire for (re-)engagement with interested parties from the European Union. Although in some of the visited countries there are very well qualified personnel in molecular biology and biosafety/regulation, the main message received is that human resources and capacity building in-house are still needed. This could be achieved through home-based courses and capacity-building including funds for post-degree research to motivate and retain trained staff.

1. Introduction

A study was undertaken to compile available information and recommendations to provide the basis for evaluating the scientific, technical and institutional challenges, priorities and bottlenecks in Africa for the uptake of biotechnologies. For the purpose of this study, the term 'biotechnology' was taken in its broad *Convention on Biodiversity* (CBD) definition in order to encompass, apart from genetically modified organisms (GMOs), molecular techniques for diagnosis and breeding, tissue culture, exploitation of naturally occurring microorganisms for fermentation, and as inoculum for crops (e.g., mycorrhizas). Using this definition rather than the narrower definition in the *Cartagena Protocol on Biosafety*, the study went beyond technology involving recombinant DNA.

The study was centred on what were termed four 'domains' of biotechnology, namely agricultural ('Green') biotechnologies, industrial ('White') biotechnologies, aquaculture ('Blue') biotechnologies, and healthcare ('Red') biotechnologies (AGRIFOR Consult, 2005), but also recognised the importance of biosafety and legal aspects of biotechnology. The study was directed primarily at the academic and scientific community in the countries visited but additional information was gained in relation to issues concerning the private sector and civil society.

The focus of the study was Africa, concentrating on West Africa. The main components were desk-based research combined with missions to target countries to evaluate the status of biotechnology and biosafety, and existing infrastructure. Stakeholders were interviewed together with evaluation of attitudes and policies towards biotechnology and biosafety, in Europe as well as Africa. Field visits were made in February 2010 to Ghana, Senegal, Mali and Burkina Faso. A number of reviews and commentary on biotechnology and biosafety relevant to the case study countries and Africa in general were consulted as part of the desk study (Andanda, 2006; AU/NEPAD, 2008; Eicher et al., 2006; GRET, 2006; IFPRI, 2008; Makinde et al., 2009; Manzella and Vapnek, 2007; Sasson, 2006; Seal et al., 2008; Vignani et al., 2010). This paper also takes into account the review of biotechnology and biosafety in Africa by Birhanu (2010) that was not available when the study was undertaken and the latest report regarding international law on biotechnology from the International Law Association (ILA, 2010).

2. General findings

The African scientific community was found to be enthusiastic that biotechnology would be productive and well received in their societies. There was generally a well-expressed desire for more collaborative partnerships with European institutions, with current support mainly being provided by North American public donors, agricultural charities and educational institutions. It was not possible to gauge public attitudes to biotechnology (especially GMOs) comprehensively but from well publicised debates in the local media, it appears that biotechnology could be considered acceptable provided the risks are well understood and managed.

It was clear that the development of new crop varieties and the exploitation of natural biodiversity (plants, microorganisms) must be linked with physical resources to conserve and store them in situ (seed banks, culture collections). A physical resource is a pre-requisite for protection of intellectual property rights (IPRs). Considerable research and development (R&D) existed in some sectors (varying from country to country) but gaps were evident between R&D and implementation and additionally, short-term funding for R&D is clearly not sustained.

Not surprisingly, many key institutions clearly lacked a sufficient body of well-trained staff; training needs were identified as a priority to augment the cadre of intermediaries (technicians) that can communicate and spread biotechnology know-how among the private production sector of each territory. However, there were a number of high quality local educational initiatives in West African countries (Masters and Doctoral level and vocational) and especially regional programmes (Rabiotech). A key issue, however, was a lack of women working in science in the case study countries compared to other regions of Africa (e.g., East Africa). Possible support for training could come from the European Commission's FP7 Research and Technology Development (RTD) programme, from the Europe Aid Co-operation Office (AIDCO) (framework contracts for policy support, major projects for development of infrastructure) and from member states (e.g., educational initiative such as SCARDA). Initiatives for 'Centres of Excellence' clearly merit support but the criteria for selection of such centres require careful evaluation. Such evaluations are currently carried out through various initiatives by NEPAD, CORAF, and other bodies.

2.1. Green biotechnology

Most stakeholders consulted agreed on the fact that conventional and modern biotechnologies provide valuable tools for the agriculture sector, although when talking about green biotechnology there has been a strong emphasis on genetically modified organisms which as a result has eclipsed attention on other biotechnologies. It is important to recognise that green biotechnology includes a suite of non-contentious technologies for improving food security such as molecular diagnostics for plant diseases, molecular assisted selection for desirable characteristic in conventional breeding and tissue culture for mass propagation of healthy planting material. The policy environment in the EU (Parliament, Commission, member states) and the prevailing public debate concerning GMOs is important for possible future strategic support for biotechnology in Africa. Important issues discussed below (Section 2.5) are the application of 'GMO-free' zones or countries, the impact of the EU labelling regime for GM-derived food on Africa and the impact of European consumers' attitudes to GMOs and GM-derived food exported from Africa.

The current R&D emphasis in Africa concerns food security and improved nutrition and hence the development of varieties that show improved resistance to other biotic as well as abiotic stresses

(e.g., drought and biofortified varieties). This should be supported provided the 'development package' includes provision of inputs such as fertilisers and water for irrigation and the appropriate technological guidance. There are few implications of this for the European market and there is evidence of deliberate avoidance of potentially exportable cash crops on the part of the organizations involved in GM crops. Bt cotton (genetically modified with *Bacillus thuringiensis* genes) currently occupies the largest area in Africa for any GM crop (ISAAA, 2009).

In general and in the visited institutions there are appropriate and useful biotechnologies in place (i.e., in vitro culture facilities, recombinant DNA technologies, genetic markers), technical and human capacities (although staff numbers are too low), and emerging policies. Information on a selection of the institutions surveyed is given in Table 1 (applying to other biotechnology domains as well as green biotechnology).

Priorities for green biotechnologies including GMOs need to be defined according to local constraints and answering the following key questions:

- Are initiatives on biotechnology still coming from outside Africa, as was the case with the first generation GM crop varieties not specifically adapted to Africa?
- Will the "new green revolution" again fail to benefit Africa in comparison to Asia?
- What steps will be taken to protect indigenous genetic resources from genetic pollution, starting with a concerted effort to acquire knowledge of these resources?
- How can biotechnology such as molecular markers and sequencing be used most successfully?

The study found that West Africa is in the advanced process of building the human and material capacity to benefit from green biotechnologies and to make up its own mind regarding issues related to biotechnology. Although infrastructure development is in some cases good, much more vital infrastructure is needed, as is increased manpower and well-trained young scientists. There is also a strong need for improvements to information exchange (through data bases), access to literature and fees for publication, and participation of scientists at international congresses. There is a need for the creation of a "virtual" platform for networking among scientists, and to promote e-learning. There is a high demand on linkages, nationally and internationally, in green (and all other) biotechnology areas. In this regard West African stakeholders are acting together and working at the regional level with support from regional institutions (NEPAD, CORAF among others). The basis of a regional cooperation is underway through the creation and operation of centres of excellence, and discussions with regard to this matter are at the forefront of the agenda in Senegal, Mali, Burkina, and the Ivory Coast.

To date, the United States Agency for International Development (USAID), National Institutes of Health (NIH), and the Bill & Melinda Gates Foundation have been the predominant donors for building biotechnology capacity building and research support towards NARS programmes in West Africa. There has been a shift from first-generation herbicide-tolerant varieties and insect-resistant cotton to locally adapted genotypes that may have advantages over conventionally bred varieties. Often, where transgenes developed in the private sector are being used, they are now linked with public–private partnerships. However, as mentioned above, equitable intellectual property ownership for African farmers and breeders is still a complex issue far from resolution.

2.2. White biotechnology (industrial and environmental biotechnology)

Summary details of blue biotechnology initiatives in West Africa are given in Table 1. In many of the West African countries visited, economic development has been driven by natural resource development projects controlled by large foreign based oil and/or mining companies. In a few of the better-functioning West African economies, industrial activities cover the whole chain of production from the extraction of raw materials to materials processing and manufacturing and final waste disposal. Key constraints for the economy and the industrial development of West Africa include (i) the lack of strategies and technologies for the sustainable disposal of urban and industrial wastes and the clean-up of wastewater and polluted areas, and (ii) the high environmental impact and lack of competitiveness of the local chemical and textile industry which still fully relies on fossil-based feed stocks.

There is growing belief and confidence that modern bioenergy and biobased products producing systems can contribute to reaching development goals, improve profits and reduce the disadvantages associated with the use of fossil fuels. Women, who currently struggle under heavy workloads that cause gender-based social imbalances and effectively exclude them from many educational opportunities and decision-making processes, can be strongly involved in this new opportunity. Sugarcane and sweet sorghum can yield ethanol at competitive costs that can be used as cooking fuel or blended with transport fuels. A number of technologies, like industrial-scale biogas production and steam turbine systems, are mature and fully commercial and can satisfy electricity demand in several agro-industries (e.g., sugar, pulp, and paper industries) and provide excess power to the grid (Greben and Oelofse, 2009). The vast African potential household market for biogas digesters has been recognised, and addressed through a new continent-wide programme namely Biogas for Better Life (www.biogasafrica.org). However, household biogas digesters for applications in agro-industries as well as ethanol producing processes, in particular the second-generation options, are white biotechnology practices that have not yet broadly penetrated these countries.

There are other severe constraints: the high environmental impact and lack of competitiveness of the local petroleum based chemical and textile industry, and the lack of sustainable approaches and technologies to the disposal of industrial wastes and the clean-up of wastewater and polluted areas; these can be mitigated through the adoption and the large scale exploitation of white biotechnology principles and processes, which might permit (i) the efficient production of a variety of bio-based chemicals, materials and fuels from local biomass of non-food origin and food processing by-products and wastes (thus improving the environmental sustainability and the competitiveness of the local conventional chemical and textile industry), and (ii) the (environmentally and economically) sustainable remediation of contaminated areas and wastewaters.

Unfortunately, such processes and strategies of white biotechnology are currently occupying only a very small industrial niche in West Africa, basically in the sole sector of the production of liquid biofuels (i.e., bio-ethanol) from indigenous and locally planted biomass (very often non food crops) (UNIDO, 2008). The bottlenecks for the sector are diverse but include a lack of adequate funding support due in part to the lack of concerted regional political commitments in this sector. Furthermore, there is a need to update laboratory equipment, and generate increased R&D manpower, and improve IPR protection strategies and tools. Currently there is only a limited involvement in this sector of society and consumer associations.

Table 1
Summary of biotechnological capacity and activities in selected West African institutions surveyed.

Country/Institution	Biotechnology capacity	Key issues
Senegal		
Laboratoire Commun de Microbiologie (LCM), Institut de Recherche pour le Développement, Institut Sénégalais de Recherches Agricoles, Université Cheikh Anta Diop de Dakar (IRD/ISRA/UCAD)	LCM: use of biotechnologies for the characterization and exploitation of microorganisms (mycorrhizas, use of the strains for metabolite production, biodegradation of organic pollutants, fermentation units). Biotechnological conversion of by-products and waste from groundnut processing for mushroom production. ISRA: micropropagation for crop development (banana, cassava, potato, jatropa, jujube).	Strong link with Masters level education.
Institut de Technologie Alimentaire	Biotechnologies useful for the production of food products, fermented food, enzymes and gum (*Xanthomonas*).	Collaboration with Belgium, Rome, US, B&M Gates Foundation, World Bank.
	Exploiting groundnut waste as above, oxidative enzymes and fertilizer; production of primary or secondary metabolites.	Target of potential market for food products in Europe.
UCAD II – IUPA (Institut Universitaire de Pêche et d'Aquaculture)	Research in fishery and aquaculture with Master and PhD programmes. Sex selection in tilapia.	Not yet much involved in international collaboration. New laboratory being built for experimental fisheries research.
The Centre de Recherches Océanographiques Dakar-Thiaroye (CRODT)	Genetic improvement of tilapia. Catch and price data collection, analysis and management. Biology and ecology of the principally exploited species; resources dynamics, evaluation and management; fisheries mitigation and commercial fisheries economics.	Collaboration with ISRA and ORSTOM (IRD).
Département de Biologie Végétale, Université Cheikh Anta Diop de Dakar	Micropropagation for crop development.	Laboratory selected by UEMOA as regional laboratory for GM detection.
	Only basic molecular biology capacity. Masters level training/technology transfer.	Collaboration with US university.
Institut Pasteur de Dakar	Reference centre for several serious tropical diseases. Production of vaccine against yellow fever. Laboratory for disease diagnosis.	Researches on human diseases such as malaria and other mosquito borne diseases.
Center for diagnostic and research in molecular medicine (CDRMM), Dakar	Sophisticated technologies for disease diagnosis and artificial insemination.	Private structure. Molecular medicine.
Inter-university centre "Incubator INNODEV", CIFRES/ESP & UCAD Dakar	Transfer of the most promising biotechnological processes developed by the Universities and Research Centres along with an expert group dealing with the Intellectual Property Protection and Management related to the microbial cultures, processes and technologies developed by the partners.	
Mali		
Laboratoire de Biologie moléculaire appliquée, Faculté des Sciences et des Techniques, Université de Bamako (FAST)	National platform for research and training with two International Masters Programmes on or involving biotechnology.	Strong link with RABIOTECH Masters Programme.
	Well equipped laboratories involved in R&D on several domains (e.g., vaccines from plants, marker assisted selection of sorghum, isolation, characterization and cultivation of soil microorganisms) for rhizosphere inoculation, biodegradation of hydrocarbons and organic pollutants, production of metabolites, enzymes or fine chemicals of industrial interest.	Trains civil society in GMO detection.
Institut d'Economie Rurale (IER)	Micropropagation for crop improvement.	Strongly involved in harmonisation of regulatory measures through CORAF
Laboratoire Commun Vétérinaire, Bamako	Well equipped molecular biology laboratories.	Strongly involved in cooperation: Europe and other countries via INCO and FP7 projects
	Preparation and pilot scale cultivation and exploitation of vaccine producing bacteria.	
Malaria research and training centre, University of Bamako	Medical and entomological of research, mainly against malaria	Transgenic mosquitoes
Burkina Faso		
Institut de l'environnement et de recherches agricoles (INERA. Kamboise)	Infrastructure and basic equipment for applied biotechnology research on plants genetics and associated viruses; genetic characterization, use of genetic markers, large scale micropropagation (sanitation, healthy seeds), use of plants to produce proteins of interest.	Interest in becoming reference laboratory for GMO detection. Extension and outreach, particularly with civil society desired.

Table 1 (*Continued*)

Country/Institution	Biotechnology capacity	Key issues
Université de Ouagadougou & Polytechnical University in Bobo-Dioulasso	Isolation and characterization and pilot scale production of bacteria capable of hydrocarbon. Degradation or the production of metabolites, enzymes or fine chemicals of industrial interest; integrated recovery (biorefinery) of by-products and wastes of the local food processing via solid phase and liquid-phase fermentation and composting; biotechnological processes for the remediation of wastewaters and soils contaminated by pesticides and hydrocarbons.	
Centre de Recherche en Sciences Biologiques Alimentaires et Nutritionnelles (CRSBAN)	Socio-economic reintegration of people in difficult situations. Project to improve land productivity.	
Institut de Recherche pour le Développement, Institut de recherche en sciences de la santé, Bobo-Dioulasso	Research on arthropod born diseases such as malaria.	Collaborates with Centre Muraz – shares Director
Ghana		
Food Research Institute, Council for Scientific and Industrial Research (CSIR)	Biotech tools to tag microorganisms in traditional fermented foods.	Collaboration with European scientists.
Crop Research Institute (CRI)	Marker assisted selection for breeding maize, yam, sweet potato, cassava. Provides outreach/advice on biofuels	Collaboration with US, China, CG Centres
Training Coordination, Global change and the Hydrological Cycle (GLOWA XT)	GLOWA Volta Project: to ensure the sustainable use of the developed decision support technologies in the Volta Basin. The GVP, together with the United Nations University (UNU) and the International Water Management Institute (IMWI) has formed a consortium that facilitates the transfer of technologies into the basin.	Consortium formed with United nations University (UNU) and the International Water Management Institute (IMWI) to facilitate transfer of technologies into the Volta basin.
International Water Management Institute (IWMI)	IWMI targets water and land management challenges faced by poor communities in the developing world/or in developing countries and through this contributes towards the achievement of the UN Millennium Development Goals (MDGs) of reducing poverty, hunger and maintaining a sustainable environment.	With Consultative Group on International Agricultural Research (CGIAR)
Accra		The Asian Development Bank (ADB) has asked IWMI to work with the Food and Agriculture Organization of the United Nations (FAO) to build network links and provide channels to make it easier for industry and research and development organizations to share information on irrigation water management. This initiative is currently being conceptualized and developed

There is a wealth of lignocellulosic non-food biomass that could be utilised for biofuel production and as feedstocks for the production of biomass-derived ('biobased') chemicals and materials, but is currently underused or used inefficiently (UNIDO, 2007). Large-scale industrial production of first generation ethanol from cassava and other starch based crops/feed stocks is only being performed to a very limited extent. There is potential for this to be increased in West Africa, but concern too that this does not use land primarily required for food security (Cai et al., 2011).

Local R&D on biofuel production from lignocellulosic biomass (second generation biofuels) is very limited, as also applies to the fields of biomonitoring and bioremediation (by using specialised microbes and plants) of industrial sites and wastewater contaminated by hydrocarbons and pesticides as well as mining areas, contaminated by heavy metals. A range of national and international R&D programmes in the area of white biotechnology are in progress in some of the main Universities and Research Centres of West Africa, as outlined in Table 1. This is taking place under the coordination of very capable and motivated young scientists/engineers and this suggest that there are good prospects for the robust implementation of this sector in the near future.

2.3. Blue biotechnology

A great opportunity to develop aquaculture was identified (Table 1) and hence this domain of biotechnology promises much although it is the least developed of the four domains. The actual diffusion of small-scale fish production in internal fresh waters, spread all over the territories where there is water, gives women income since they are the main actors, and provides an important source of animal protein in a general situation of poverty and food insecurity. The presence of this diffused fish production is the basis to develop and apply new aquaculture technologies and, where the research conditions and the production sector can permit, biotechnologies, to increase this type of production and the economy of this depressed area. In some specific cases, where conventional aquaculture technology cannot give the appropriate answers, the application of biotechnology can help this sector to develop and select stronger species better to perform to the limited climate conditions of these areas, select and use modified bacteria for the process of fermentation, or select fish that can increase fish oil production.

At the moment fish production of the internal water resource is underutilised. All other opportunities of development are in a similar state, such as the exploitation of algae, secondary products of fish transformation, the production of fish oil, the use of waste biomass

to produce energy, and the improvement and increase of the actual scale of inland and marine fish production, with the application of new models for fish farms. Respect for the autochthonous fish species and the different local ecosystems, and defence from the introduction of alien species or modified alien organisms is of prime importance. The priority must be to work on local species (also with genetic studies using biotechnologies) and to increase knowledge of the internal fresh water fish and algal species.

The main activities in aquaculture in Senegal were related to the growth of tilapia, with four autochthonous species common in the fresh and brackish water. The principal activities are on crossbreeding of these species particularly tilapia, to find stronger and faster growth rates in different ecosystems of the country (Eknath et al., 2007). In some areas of northern Senegal a species of algae (*Spirulina*) is also being produced in order to provide food supplements for first years of life of undernourished children. UNICEF estimates that malnutrition is the cause of one in two deaths among children under the age of five, and that several tens of millions of children suffer from this condition. This as an example of a high level of technology applied to the blue biotechnology domain already present on the territory with potential for further development.

2.4. Red biotechnology

In the three visited countries (Senegal, Mali, Burkina Faso), there are research centres that are competent in the field of red biotechnologies (Table 1). There is great potential and positive public opinion for red biotechnologies to bring a vast domain of powerful tools and processes to achieve better human health in Africa, most notably improved diagnostics by molecular techniques, better targeting of pathogens and a better knowledge of their sensitivities to drugs to permit better treatment. Although research into red biotechnologies often first concentrates on producing diagnostic tools for infectious diseases, it also has to facilitate the dissemination of kits for the identification of resistance against antiparasitic drugs or antibiotics, particularly for bacterial strains with high epidemic potential.

In the diagnostic domain, a recent accomplishment of red biotechnologies, presented here as an example, illustrates how a red biotechnology may be useful. While mortality from malaria is estimated at over one million deaths annually in tropical Africa, the diagnosis has long been based solely on clinical symptoms (mostly fever), of little value. A rapid test for the diagnosis of malaria is now available using an ELISA-based stick giving a colour reaction at the patient bedside. This diagnostic kit, sold at a reasonable price, provides a reliable 'yes–no' answer with regard to the presence of the malaria-causing *Plasmodium* parasite in the blood. This information guides treatment to prescribe, permits specification of the proportion of malaria in the febrile diseases, and allows the monitoring of control operations on a large scale against the disease. Such rapid tests are now for sale in pharmacies in Africa. They are also distributed to a large panel of users in national health structures through the financial support of funding institutions, primarily the Global Fund to fight AIDS, tuberculosis and malaria that collects funds from various public and private origins (including USA, France, UK, Japan, Germany, European Commission, Bill & Melinda Gates Foundation).

There is also a need to develop African national regulatory infrastructure allowing the recording and the pharmacological scrutiny of products launched on the market, as well as being suitable for available technical skills, appropriate regulatory measures, and implementation in the various sectors (vaccines, antisera and drugs).

The authors conclude that Investment aimed at development assistance to countries in West Africa must exclude overly sophisticated biotechnologies, especially those implemented by "turnkey" projects that are not sustainable. New technologies must also be particularly reliable as they are generally not alternatives to, or replacements for, existing technologies. Red biotechnologies are poorly envisaged in various trainings devoted to biotechnologies. For instance there is only one training scheme for graduate bio-medical technicians (in Diourbel, Senegal; course of three years duration). A similar training is envisaged in the short term in Ouidah, Benin. In Bamako, Mali, an International Masters of biotechnology and biosafety, is in development. It envisages five main sections: biosafety, plant biotechnology, agriculture and environment microbial biotechnology, animal biotechnology, food-processing biotechnology. Presently there is no section envisaged for red biotechnology.

2.5. Legal aspects of biotechnology – biosafety and intellectual property rights (IPR)

The 2010 report of the Biotechnology Law Committee of the International Law Association (ILA, 2010) summarises current global issues. The report validly emphasises that many different areas of law are relevant to biotechnology, including human rights and bioethics, intellectual property rights (IPR), market access and trade regulation and international environmental law. The first legal aspect of biotechnology to be considered in this review is its regulation – biosafety. The second aspect is IPR. As an introduction to the discussion of relevant biosafety issues, a paragraph from COM (2002) is quoted under from "Europe's responsibilities to the developing world" (p. 19):

> 'Europe should encourage equitable and balanced North–South partnerships and public research for demand-driven applications of life sciences and biotechnology. Domestic European policies with regard to life sciences and biotechnology are bound to have major impacts on developing countries. Whilst not compromising EU food safety requirements or consumer information policies, we should provide technical assistance and capacity building to ensure that our policies do not, unwittingly, prevent developing countries from harvesting desired benefits. In particular, we should guard against regulatory requirements that may be manageable only in the industrial world but are unachievable by developing countries, thereby either upsetting existing trade or effectively blocking developing countries from developing life sciences and biotechnology at their own wish and pace.'

Echoing these sentiments, several persons interviewed held that biosafety regimes adopted in Africa mirrored Europe's too closely and were unnecessarily restrictive. (Africa Harvest: 'Too many layers – Africa needs relevant system ignoring politics in EU'.) Also, NEPAD's Biosafety coordinator saw the AU' Model Law on Biosafety, as a 'gift' from the EU that was too restrictive.

2.5.1. Biosafety initiatives in Africa

It is now pertinent to begin the discussion by what the study uncovered about disparate attitudes towards biotechnology and its regulation in various African countries. This information was obtained by interviews with African contacts and from media reports about the controversies. These differences provide important context for the attempts at regional harmonisation of biosafety. Ghana provides an instructive example. On the one hand, Friends of the Earth Ghana and other pressure groups have effectively blocked Cabinet approval of the 2004 Biosafety Bill by successfully arguing that a new law will merely give the green light to a flood of GMOs and GM food into Ghana in spite of public opposition (Ghana Web, 2009).

By contrast, groups aligned with the government and scientific community claim that there is little public concern provided

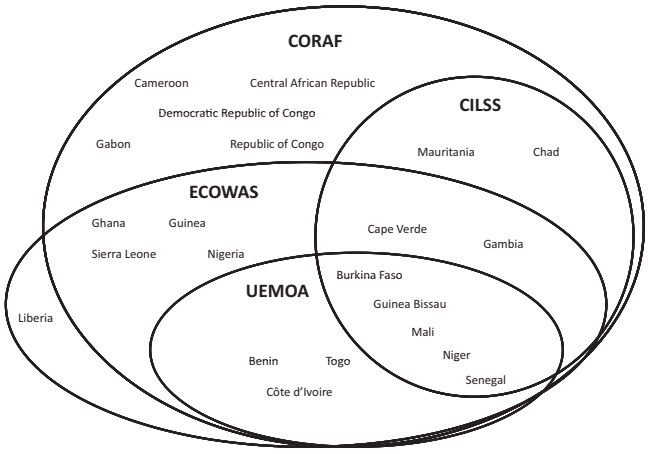

Fig. 1. Sub-regional organisations in Central & West Africa (adapted from IFPRI, 2008). ECOWAS: Regional Biosafety Initiative. UEMOA: Regional System for Biosafety. CILSS: Framework Convention on Biosafety.

that approval is given to GMOs after proper evaluation. In other words, the law is seen essential to proper regulation of biotechnology (IPS News, 2009). This debate was mirrored in Mali but after lengthy consultation with civil society and other parties, Parliament adopted a biosafety law (2009) that is regarded as closest to the African model law (La Via Campesina, 2008).

In February 2010, the Malian Ministry of Environment a held consultations with civil society which resulted in secondary legislation ('textes d'application') so that the law can now be implemented. Mali also provides the Nodal Office for ABNE. Burkina Faso was first Francophone African country to adopt a biosafety law (2003) and has since gone furthest in commercial cultivation of Bt cotton (15,000 ha). However, there has been very active opposition (anti-Monsanto basis) with crop trials destroyed. In Togo it is significant that a very cautious approach to GMOs is being taken with risk-assessment including socio-economic factors, which in itself is quite controversial because in some jurisdictions risk assessment should only include 'real' science. Benin has imposed a five-year moratorium on GM crops (GRAIN, 2005). Birhanu (2010) has examined this disparity by looking at the degree of caution towards GMOs displayed in national regulatory frameworks in six countries, but none of these were in West Africa.

Against this disparity, one may ask what are the prospects for regional (African) or West African harmonisation of biosafety? The overall context is the complex of regional organisations active in biotechnology and biosafety in West Africa, often overlapping in their jurisdiction (Fig. 1).

For Africa as a whole, the UEMOA initiative to establish a regional regulatory system with support from the World Bank (see below) has been criticized by African and international civil society organs that oppose the introduction of Bt cotton; these organisation active in the region expressed concern that the project would "promote favourable regulations in a few key countries" and then "use these regulations as a model that can be imposed on neighbouring countries by regional bodies" while side-stepping democratic debates. Progress up to 2008 has been reviewed by IFPRI (2008). In fact, until 2007 there were three initiatives (CILSS, CEDEAO, UEMOA) with elements of competition between them, but in August 2009 in Abuja, Nigeria, it was decided to aim for one unique and common biosafety programme. There is currently no support from the EU to any of these initiatives, a topic addressed in the final section. A further complication is that some of the organisations involved (e.g., CORAF/WECARD) are not official bodies but scientific cooperation/advisory bodies; each may be aligned with a particular regional body and have links with partners in developed countries.

The key issues identified can be summarised as follows:

- Consequent on the disparity of attitudes to GMOs, and in spite of several initiatives for regional and sub-regional harmonisation (with now a high degree of coordination among them), it is difficult to find an appropriate model for such harmonisation without a commonly agreed sense of purpose.
- The achievement of national capacity to enforce biosafety will largely depend on successful (sub-)regional coordination.
- The application of the concept of 'GMO-free' areas in Africa as desired in some countries requires careful examination as there may be a conflict between freedom of consumer choice for GMO-free environment and commercial freedom to grow crops for which there is a market.
- Risk assessment is at the heart of any regulatory system that purports to make informed decisions about the approval and adoption of biotechnology. There are unresolved tensions about the inclusion of 'socio-economic impact' in risk assessment that would, for example, take into account lack of public acceptance of a particular biotechnology.
- Accounting for 'uncertainty' is the key to risk assessments that will meet political requirements and that will overcome the controversy over the Precautionary Principle.

While not compromising EU food safety requirements or consumer information policies, technical assistance and capacity building are necessary to ensure that EU policies do not, unwittingly, have undesired effects, particularly in terms of regulatory requirements that may upset existing trade or effectively block developing countries from integrating biotechnology. The misconception that the stringent labelling regime for GM-derived food in the EU is actually a ban was expressed by many of the Study's African interlocutors. Conversely, EU policy makers should be made aware that the use of recombinant technology in Africa is not likely to result in GM food destined for European markets.

At the African level, NEPAD (Office of Science & Technology) has established the African Biosafety Network of Expertise (ABNE) conceived to facilitate functional networks. The AU's initiative on the other hand is primarily on the diplomatic front by promoting representation of Africa in international fora on biosafety. Additionally, before taking any Africa-wide initiative, the AU needs inputs from all sub-regions.

2.5.2. African union model law on biosafety

Reference has already been made to this model law already and the view taken by some that it is too restrictive, being based on EC legislation (Section 2.5.1 above). On the other hand, the preamble correctly addresses both the potential benefit and risks of GMOs and significantly addresses the 'need to deal with imports of genetically modified food through aid or trade'. It is also noted that the definition of 'risk assessment' (Article 2) is defined to include "socio-economic consideration and ethical values of the country" which was discussed above in the survey of biosafety in West African countries. Approval of GMOs under Article 8.7 depends on such considerations being satisfactory.

Birhanu (2010) has examined substantive aspects of the Model Law in detail. The more general issue raised by the present authors is whether a 'model law' is appropriate by virtue of being written in legal language and therefore containing some legal concepts that might not be acceptable in certain jurisdictions. In any case a model law has to be 'adapted' and not 'adopted'. The strength or otherwise of any law is something for the national authorities to decide and judgment over whether a model law is 'too strong' or 'too weak' may be premature before it is adapted by an individual nation. This is exemplified by the provisions for liability and redress (Article 17)

that go far beyond Cartagena and in fact mirror developments in the EU (Birhanu, 2010).

Rather than being too 'restrictive', perhaps the Model Law should be seen as too 'prescriptive' in the sense of embodying legal concepts that might not be appropriate. One conclusion of the study was that 'guidelines' or 'directives' might be more appropriate as a source for primary biosafety law (Act of Parliament or Loi). On the other hand, it was easier to draft secondary legislation (regulations, etc.) from a model because such legislation had more technical content than legal principles. This leads to key points made in Section 3 on legal drafting resources and support from the EU.

2.5.3. Social acceptance of GMOs and GMO-free zones/countries

Article 19 of The African Union Model Law ('Community Rights for GM Free Zones') states the following:

> Taking into account the provisions of Article 26 of the Cartagena Protocol on Biosafety and the provisions of the Convention on Biological Diversity on the conservation and sustainable utilization of biological diversity:
>
> 1. The Competent Authority shall develop policies that protect the rights of Communities to declare GMO free zones.
> 2. The Competent Authority shall take measures for the creation of geographical areas that are declared as 'GMO free zones' where the release of any GMO is prohibited.

Countries such as Zambia have stood out against GMOs and GM-food entirely. To avoid criticism of political bias, Zambian's objections were based on preventing destruction of farmers' varieties by GM pollen. It remains to be established whether such a stance helps or hinders national development and secondly whether such legal moves can prevent the entry of GMOs by pollen blowing across borders and informal trade or germplasm exchange. However, it is noteworthy that Zambia is one of few sub-Saharan African countries with GMO detection infrastructure.

Regarding possible future policy support for biosafety initiatives in (West) Africa it is worth quoting comments in "Guidelines on Green, Blue, Red and White Biotechnologies" (AGRIFOR Consult, 2005):

> Public mechanisms for social–ethical scrutiny are thus essential elements of governance of pro-poor biotechnology development in developing countries. Biotechnologies might provide the most efficient technical means to address a problem, but that problem first requires being carefully analysed by the stakeholders affected, in order to establish the different perspectives and solutions available to the developing country so as to agree upon the most appropriate actions for pro-poor biotechnology development. The EU should therefore support initiatives at regional level, enabling the development and implementation of national public mechanisms for social–ethical scrutiny of pro-poor biotechnology development in developing countries (AGRIFOR Consult, 2005).

2.5.4. Africa's particular difficulties in harmonisation

An irony of development in Africa that attempts at legalising cross-border transfer of food (particular in times of famine in one area and surplus in another) or germplasm meet with political resistance but there can be very active informal cross-border trade and germplasm exchange because of porous borders. At the same time, wind-blown pollen may easily cross borders. Given also the disparity in attitudes to GMOs and biosafety in different countries, and notwithstanding the sub-regional initiatives described above, the prospects for harmonisation, and the type of harmonisation, must be examined closely.

There can be no biosafety without biotechnology. For example, biotechnology for detecting transgenes in food and living organisms is essential determining for compliance with a regulatory regime. Any 'permissive' regime based on labelling or a regime that recognises consumers' rights to information will make similar demands on biotechnology. However, if GMOs or GMO products enter a country through informal cross-border trade or by pollen in the wind, the cost-effectiveness of regulation backed by technology must be questioned. In this context must be placed policies towards food aid that require grain to be milled before shipment to prevent farmers planting the grain and potentially damaging local biodiversity by the spread of GM pollen. The authors return to a major conclusion that the priority is seed banks to conserve local crop varieties physically and in terms of IPR, another essential component of biotechnology. Whether any particular regulatory regime is permissive or cautious (Birhanu, 2010) should be taken in this context.

So far all the consideration on biosafety has been on GMOs (crops) in land-based systems. As Section 2.3 shows, aquatic biotechnology is in its infancy in West Africa and as far as is known there are no plans to introduce GM fish or crustacea in the region. However, any introduced non-GM aquatic species pose risk to the environment if they escape from ponds or caged environment as seems inevitable eventually. It is well known that alien species are much more invasive and destructive of habitats in aquatic than in terrestrial systems (Black and Kireeva, 2010).

2.5.5. IPR in biotechnology as affecting GMOs in Africa

The second legal aspect to be considered is intellectual property law relating to biotechnology. This is very complex, involving, *inter alia* a conflict of public interests expressed in the Convention on Biodiversity (CBD) and private/commercial interests expressed in the *Agreement on Trade-Related Intellectual Property Rights* (TRIPS) (ILA, 2010). The High Level Panel on Biosafety refers to the 'IP maze' (AU/NEPAD, 2008), echoing the complexity of this issue. It is only possible to present a summary of the subject in the context of this study but which nonetheless points to some future directions of strategy for biotechnology. As background a few major issues are outlined before a more detailed treatment.

At the heart of the issue is the apparent conflict of access rights (Article 15) and benefit-sharing arrangements (Article 19) under the CBD with TRIPS that appears to allow exploitation of natural resources in countries that do not have IP protection of natural resources. This makes discoveries (by bioprospecting) of useful organisms, genes, enzymes, etc. vulnerable to 'biopiracy'. It also affects farmers and/or breeders rights to traditional plant varieties and animal breeds and to GMOs which are developed in or for developing countries. It also brings in the issue of sustainable means of conserving natural resources in situ with seed banks, microbial collections, etc. (see above).

On the positive side, however, there has been a shift in attitude towards ownership of GMOs developed for developing countries. Whereas the first generation of GMOs developed for temperate countries were clearly the private IP of the biotechnology companies, most recent GMO development in South for food production has been publicly funded (AGRIFOR Consult, 2005) with funding from charitable foundations (e.g., Gates) as well as national and international development agencies. (It must be acknowledged that 'donation' of commercially developed genes may be facilitated by licensing fees obtained from their use in the developed world.) There were positive signs that biotechnology developed for or in the developing countries studied will be secured as public property or freely licensed for public use in such initiatives as the African Agricultural Technology Foundation (AATF).

As mentioned above, however, there has been a shift in concepts of IP ownership regarding resources for the South. Most genes remain privately patented but the new concept is a 'protected technology commons' for the South (AGRIFOR Consult, 2005). There have been IP difficulties in developing new GM crop varieties (e.g., "golden rice") within the CGIAR system. For example, private companies are able to obtain germplasm generated by the CGIAR system and then market modified varieties under patent so profits go back to them, without any compensation to developers (or country of origin) of the previous variety (AGRIFOR Consult, 2005).

Some examples of initiatives to overcome these problems are: African Agricultural Technology Foundation (AATF) [DFID, Rockefeller Foundation, USAID] (Seal et al., 2008) [ISAAA AfriCentre http://africenter.isaaa.org]; Public Intellectual Resource for Agriculture (PIPRA) [Very wide support and membership from universities and public foundations worldwide http://www.pipra.org/about/]; BIOS (an open source initiative equivalent to Linux) [http://www.patentlens.net/daisy/bios/169/version/live/part/4/data].

Additionally, the development community has sponsored local initiatives to patent such things as herbal medicines where the appropriate legal system exists (e.g., India). The fact remains, however, that many African countries have only a rudimentary or obsolete patent system if any and may lack laws to protect plant varieties.

In 2008 the UN initiated consultations on a 'roadmap to curb biopiracy' (SciDev Net, 2010). Serious attention to training in IPR for scientists and jurists among developing countries including staff of CGIAR centres was recommended in several studies including the influential 'Guidelines' report (AGRIFOR Consult, 2005). This is supported by the authors.

3. Forward-looking approaches to biotechnologies in Africa

There are many non-controversial aspects of biotechnology that could be of great benefit to African food producers and consumers. Whereas Bt cotton currently occupies the greatest area devoted to GM crops, there should be recognition that many crop varieties for food currently being developed (or being envisaged) in Africa are the product of public initiatives or private/public partnerships and are intended to improve food security and/or nutritional content and therefore will have little impact on European markets or consumers. Birhanu's (2010) conclusion that "little attempt has so far been made to develop GM varieties that address the real needs of Africa" may not hold true for the future and may be painting Africa today with too broad a brush. However, the assessment that "the technology is owned by the private seed industry, often protected by intellectual property rights, so making varieties expensive and inaccessible to poverty-stricken farmers in Africa" seems likely to remain accurate.

Several of this study's African interlocutors had interpreted events in Europe as the EU banning GM food, whereas in fact the restrictions were merely referring to the stringent labelling requirements. Whereas food labelling to indicate GM content may be necessary in Africa to satisfy equivalent consumer demands, the EU labelling, and GM approval, regimes cannot simply be copied. EU Delegations in African countries/sub-regions should be sensitised to these policy issues in biotechnology and involved in ongoing initiatives. A separate study is recommended to examine in detail societal and ethical issues relating to biotechnologies, particularly GMOs, which was unfortunately beyond the scope of the study reported here.

3.1. Green biotechnologies

Discussions held during this study identified that in the field of green biotechnology there were some priority needs expressed as outlined in Table 2.

The European community should facilitate effective mechanisms for South–South collaboration, through biotechnologies platforms, sharing skills and knowledge with other countries in the region, providing access to information, and ensuring access to new technologies in a fair and economically profitable way. The European community should play a major role in supporting West-African countries by providing funding to support these activities, and also by facilitating regional and international cooperation through support to biotechnology centres and by promoting partnerships with EU and their key institutions.

3.2. White biotechnologies

Financial support is essential to ensure the success of the White Biotechnology R&D priorities, in particular the establishment of local biorefineries exploiting local lignocellulosic biomasses and agrifood industry by-products and wastes with the production of biobased products and fuels. This could be accomplished within the framework of dedicated small-scale collaborative R&D projects involving experienced partners from EU and West Africa. Indeed, a close cooperation between academics/SMEs involved in the development of the innovation in the biorefinery area in Europe and qualified West Africa researchers would guarantee the successful implementation of the biorefinery concept on local non-food biomass feedstocks. Other priorities which require lower and only local R&D and IPR development, could be implemented through projects supporting the transfer and local implementation of technologies already well established and assessed in Europe. Examples include:

i. the large scale adoption of anaerobic digestion facilities for converting local organic wastes in biogas for heat and electricity production;
ii. the large scale adoption of techniques for the microbial- and/or phytoremediation of contaminated matrices, mining and industrial sites and waste waters, etc.

It was considered that projects, such as the EU 'Marie-Curie' actions, designed to boost West African young scientists/engineers training in Europe would be of great benefit to the effective implementation of white biotechnology and the knowledge-based 'Bio-Economy' in the sub-region.

3.3. Blue biotechnologies

It is recognised that blue biotechnology may be at an earlier stage of development than some of the other domains of biotechnology in this sub-region. It is important to underline that only by increasing knowledge is it possible to understand the correct approach to this delicate sector and comprehend the great opportunity to develop biotechnology in the field of aquatic organisms, protection of natural resources and autochthonous species, agriculture, health and industry. For this reason the priority is to develop and increase good educational and training programmes in the state universities and research organs, and to facilitate collaborations between them.

A second level of training needs to target technicians that could apply and distribute these technologies and facilitate their application in the different sectors. An African excellence centre could give a good level of warranty for positive feedback and it is important to concentrate the efforts on these centres of excellence, with

Table 2
Suggested concrete actions for green biotechnology and other biotechnology domains.

Green biotechnology
• Development of biotechnological applications for improving tolerance to biotic stress: from the field to the lab and vice versa
• Development of detection methods for plant pests and pathogens of major staple crops (e.g., cassava, yam, potato, rice, maize, sorghum, banana)
• Mining genomics information of plant pathogens to understand genetic basis of genotypes and its application for breeding for sustainable plant production in Africa
• Assessing impact/effect of environmental change on the occurrence and distribution of new emerging pests and diseases and other possible stresses on major staple food crops in Africa
• Development of markers and biotechnological tools for GMO detection in West-Africa
• Development and optimization of methods to maintain plant and related microorganism biodiversity in West Africa
• Innovative biotechnology for vaccine production using food crops
• Develop support for marker assisted selection for resistance to biotic stresses
General application
• Consolidate alliances with Europe in the field of agriculture in West-Africa
• Promoting global and regional cooperation in Africa to accelerate knowledge transfer on:
- Biotic stress tolerance of major staple food crops
- GMOs detection
- Link biotic and abiotic stress tolerance research
• Supporting governance in agricultural biotechnologies research and establishment of centres of excellence in West-Africa
• From the lab to the field: support specific dissemination action to potential users (e.g., farmers, civil society)
• Support AFRICA-nets (ex networking activities on GMO detection)
Training
• Support PhD programmes (European fellowship programme in Africa /Europe) and support integration programme in the country of origin
• Support development of "young research" team and international networking laboratories (Africa/Europe)

funding limited to the highest quality projects, and avoid helping a great number of projects without, at the end, consistent practical results. The first step of a new age of collaborations then would be to provide incentives for a constructive cooperation between the European aquaculture and fishery research centres and the African Centres of Research Excellence, promoting programmes of exchange, of PhD and Master students and technicians between developing countries and Europe.

3.4. Red biotechnologies

Red biotechnology was considered to include not only components such as immunoassay kits for diagnostic tests, sequencing and bioinformatics, cell and tissue cultures, and GMOs, but also areas partially covered by these biotechnologies (e.g., telemedicine, medical imaging, nanotechnology, purely chemical processes, good laboratory practices, biosafety and bioethics). It is necessary to make a clear distinction between research and utilisation, which despite being in reciprocal interactions, like two mirrors, are distinct, especially in the realm of red biotechnology.

Investment in a perspective of development assistance to countries in West Africa must exclude the sophisticated biotechnologies, implemented by "turnkey" projects. They must also be particularly reliable, as far as they are generally used without alternatives (by filling a gap or by substituting itself for an already existing technique). In the longer term, funding should be invested in promoting the emergence of a sector of companies strongly connected to the sector of research to establish a continuum in red biotechnologies between R&D.

The involvement of the EU in the Global Fund against malaria, AIDS and tuberculosis, already real, should be strengthened according to current means of support. To aid the provision of much-needed new drugs and vaccines in Africa, the EU needs to strengthen its involvement in the European & Developing Countries Clinical Trials Partnership (EDCTP) or similar structures that are dedicated to clinical trials in developing countries.

The development of African regional and national systems is necessary to allow the recording and monitoring of pharmaceutical products launched on the market. It has to appeal to technical skills and appropriate regulatory measures, as well as in the implementation of independent infrastructures allowing the respect for the procedures for vaccines, anti-venomous serum, or drugs. Local technological capacities intended for the pre-clinical stages (identification of active ingredients, toxicity testing, absorption qualities, etc.) must be strengthened.

3.5. Legal/policy issues

There are many policy and legal issues that need to be resolved within the West African countries included in this study, before there can be significant progress towards regional harmony of biosafety and other legal aspects of biotechnology. Policy support and support for legislative and regulatory initiatives should be provided in the following areas at national, regional (African) and sub-regional level.

3.5.1. Ethics and human rights

Recognition needs to be given to the rights to information, ethical issues over food and commodity miles, and the importance of uncertainty in risk assessment. Consideration will need to be paid to whether a rights acquisition and rights management policy is applicable based on practical grounds, and respect paid to the privacy of data.

3.5.2. Socio-legal issues

In national biosafety law, the issue of allowing GMO communities to declare themselves 'GMO'-free must be examined carefully. Choice should be allowed on a voluntary/cooperative basis but this must not restrict the right of individual farmers or food processors to grow GM crops within the provisions of the law.

3.5.3. Biosafety legislation

It is recommended to support a move away from a Model Law as this is too prescriptive for the development of Guidelines or Directives for biosafety legislation. In any case, there should be support for administrators and jurists to prepare preliminary instructions and for drafting jurists to understand technical issues, thereby encouraging feedback between instructions and legal text. Consensus is needed on the purpose of the law in order to facilitate regional harmonisation, given disparity of socio-legal conditions. Another recommendation is for a recognition that the EU labelling regime is too complicated and stringent for Africa and thus the need for an appropriate regional system.

3.5.4. Intellectual property law

Initiatives need to be supported to make IPR in natural resources and biotechnology fairer for developing countries (ILA, 2010), and this will be assisted by IPR training being given to targeted scientists and jurists.

3.6. Cross-cutting issues

One of the overriding conclusions to be drawn from the study was that rigid divisions between the four domains of biotechnology should not be made where there are obvious linkages. The first example that comes to mind is utilisation of agricultural residues in fermentation. However the following cases of integration between green and white biotechnology domains were also observed:

i. selection, amelioration and development of energy crops tailored for growing in arid or non-cultivated areas of West Africa,
ii. selection, amelioration and preparation of autochthonous plants able to produce tailored biochemicals and biomaterials for the pharmaceutical, cosmetic and/or chemical industry
iii. selection of local plants from polluted industrial or mining areas with an improved ability to remove heavy metals and organics from contaminated soils, sites and wastewaters (phyto- and rhizoremediation).

Another cross-cutting issue is the concept of Centres of Excellence being pursued by some regional and sub-regional programmes of coordination and harmonisation. However, this concept requires some care in its application in order to take account of national sensitivities and the work of the CGIAR centres. Criteria on which such centres are adopted (e.g., crop specialisation or degree of sophistication of facilities) needs evaluation. This applies particularly to the direction of further development of WABNet as the sub-regional biotechnology network (now based in Dakar); at the moment this is only a biotechnology network. Should it develop along the lines of BECANet (East and Central Africa) as a well-endowed laboratory-based resource? Overall, caution should be exercised in order to avoid extreme competition between institutions that would restrict a frank collaboration between these centres.

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Contributors

All authors have materially participated in the research and in the article preparation, according to the following scheme: Robert Black: coordinator of the study and legal/regulatory expert; corresponding author. Fabio Fava: 'white biotechnology' expert in the study. Niccolo Mattei: 'blue biotechnology' expert of the study. Vincent Robert: 'red biotechnology' expert of the study. Susan Seal: biotechnology adviser to ECART*/AGRINATURA and coordinating author of the paper (*ECART was primary contractor of the EU-funded study). Valérie Verdier: 'green biotechnology' expert of the study.

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