UNIVERSITY OF CAPE COAST

TECHNOLOGICAL CAPACITY BUILDING IN DEVELOPING COUNTRIES – A CASE OF CROP BIOTECHNOLOGY IN GHANA

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TECHNOLOGICAL CAPACITY BUILDING IN DEVELOPING COUNTRIES – A CASE OF CROP BIOTECHNOLOGY IN GHANA

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Dedicated to

The Essegbey family

DECLARATION

I do hereby declare that except references to other people's works, which I have duly acknowledged, this thesis is the result of my own research and that in no previous application for a degree in this University or elsewhere has this work been presented.

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ABSTRACT

This thesis assesses the state of biotechnology in Ghana. It shows the present status of biotechnology in terms of the physical facilities, human resources, information resources and the organisational system through, among other things, a survey of biotechnology-related scientific institutions including research institutes and universities in the country.

The study also conducts a case study of 295 farmers in the New Juaben District to assess the potential demand for biotechnology innovations. The New Juaben District was randomly selected from the districts in the Eastern Region, which was ranked first in the production of food crops such as maize, cassava and plantain using data from the Ministry of Food and Agriculture.

The study further analyses current biotechnology trends, examining the experiences of other countries such as Kenya, Korea, South Africa and the U.S. to establish the best practice in building capacity for biotechnology development. On this basis, the study generates some policy options for the advancement of biotechnological capacity development in Ghana.

The findings are that in Ghana, the capacity for biotechnology innovations is generally limited. This is in spite of the fact that with respect to innovation supply, there is a significant core of human resource capable of addressing some of the country's agricultural problems. However, physical facilities are inadequate or completely lacking

and the informational resources are limited. Besides, the organisational framework needs improvement especially as regards regulation and coordination to ensure impact of the various initiatives in biotechnological capacity development.

On the demand side, researchers working on the on-farm problems of low yields, crop diseases, etc are apparently addressing farmers' expectations. However, there is a gap between the scientific community and the farming community. The present extension service according to the farmers can be an effective system for addressing this problem. Nevertheless there is need for improvement in order to make the transfer of biotechnology innovations to farmers more effective. Thus, there is the need for a more viable linkage between supply and demand for innovation.

The best practice as derived from the experiences of other countries such as South Africa, Kenya, Brazil, Mexico, Korea and the U.S. calls for among other things, establishing a national priority area for biotechnology application. This must be based on the country's national endowment and its development aspirations. The relevant human resource must be enhanced and the relevant policies for regulation and promotion must be formulated. Above all, there must be a national biotechnology programme formulated through a holistic approach to ensure synergy in biotechnological capacity building.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACP - African Carribean Pacific
AEA - Agricultural Extension Assistant
AEO - Agricultural Extension Officer
AGSSIP - Agricultural Service Sector Improvement Programme
B.Sc. - Bachelor of Science
BETCEN - Biotechnology Education and Training Centre (South Africa)
BNARI - Biotechnology and Nuclear Agricultural Research Institute
CBD - Convention on Biological Diversity
CENIC - National Centre for Scientific Research (Cuba)
CEPS - Custom, Excise and Preventive Service
CFC - Common Fund for Commodities
CIB - Centre for Biological Research (Cuba)
CIDA - Canadian International Development Agency
CIGB - Centre for Genetic Engineering and Biotechnology (Cuba)
CINVESTAV - Centre for Research and Advanced Studies (Mexico)
CIP - International Potato Centre (Peru)
COCOBOD - Cocoa Board
CONACYT - National Council for Science and Technology (Mexico)
CRI - Crops Research Institute
CRIG - Cocoa Research Institute of Ghana
CSIR - Council for Scientific and Industrial Research
CSPWD - Cape Saint Paul Wilt Disease

CSSD	-	Cocoa Swollen Shoot Disease
CTA	-	Technical Centre for Agricultural and Rural Cooperation
CYMMNT	-	Centro Internacional de Mejoramiento de Maiz y Trigo – International Centre for Maize and Wheat Improvement (Mexico)
DAEO	-	District Agricultural Extension Officers
DANIDA	-	Danish International Development Agency
DFID	-	Department for International Development
DNA	-	Deoxyribonucleic acid
EBI	-	European Bioinformatics Institute (U.K.)
ELISA	-	Enzyme Linked Immunosorbent Assay
EMBRAPA	-	Brazilian Agricultural Research Enterprise
EPA	-	Environmental Protection Agency
ERP	-	Economic Recovery Programme
ESCAP	-	Economic and Social Commission for Asia and Pacific
EU	-	European Union
FAO	-	Food and Agriculture Organisation
FDB	-	Food and Drugs Board
FORIG	-	Forest Research Institute of Ghana
FRI	-	Food Research Institute
GAEC	-	Ghana Atomic Energy Commission
GAINS	-	Ghana Agricultural Information Service
GDP	-	Gross Domestic Product
GEPC	-	Ghana Export Promotion Council
GGDP	-	Ghana Grains Development Programme

GHAGRI	-	Ghana Agricultural Research Information
GMO	-	Genetically Modified Organism
IAEA	-	International Atomic Energy Agency
ICGEB	-	International Centre for Genetic Engineering and Biotechnology
IITA	-	International Institute for Tropical Agriculture
INIFAP	-	National Agricultural Research Institute for Potatoes (Mexico)
IRPA	-	Intensified Research in Priority Areas (Malaysia)
ISNAR	-	International Service for National Agricultural Research
ISSER	-	Institute of Social, Statistical and Economic Research
ITC	-	Indigenous Technological Capability
IUCN	-	The World Conservation Union
J.S.S.	-	Junior Secondary School
KARI	-	Kenya Agricultural Research Institute
KNUST	-	Kwame Nkrumah University of Science and Technology
LMO	-	Living Modified Organism
M.Sc.	-	Master of Science
MAB	-	Monoclonal Antibody
MAS	-	Marker Assisted System
MCT	-	Ministry of Science and Technology (Brazil)
MEST	-	Ministry of Environment, Science and Technology
MOFA	-	Ministry of Food and Agriculture
MT	-	Metric Ton
NARP	-	National Agricultural Research Programme

NBD	-	National Biotechnology Directorate (Malaysia)
NCST	-	National Council for Science and Technology (Kenya)
NIH	-	National Institute of Health (U.S.A.)
NIS	-	National Innovation System
NRCD	-	National Redemption Council Decree
ODA	-	Overseas Development Agency
OPRI	-	Oil Palm Research Institute
PCR	-	Polymerase Chain Reaction
PGRC	-	Plant Genetic Resources Centre
Ph.D.	-	Doctor of Philosophy
PNA	-	National Alcohol Programme (Brazil)
QAS	-	Question and Answer Service
R&D	-	Research and Development
R&D	-	Research and Development
RAPD	-	Random Amplified Polymorphic DNA
RFLP	-	Restriction Fragment Length Polymorphism
S&T	-	Science and Technology
SAGENE	-	South African Committee for Genetic Experimentation
SAP	-	Structural Adjustment Programme
SARI	-	Savanna Agricultural Research Institute
SBIO	-	Special Biotechnology Secretariat (Brazil)
SCP	-	Single Cell Protein
SRID	-	Statistics, Research and Information Directorate
STEPRI	-	Science and Technology Policy Research Institute
TAP	-	Technology Atlas Project

TEEAL	-	The Essential Electronic Agricultural Library
TRIP	-	Trade Related Aspects of Intellectual Property Rights
U.C.C.	-	University of Cape Coast
U.G.	-	University of Ghana
U.K.	-	United Kingdom
U.S	-	United States
UNAC	-	Universidad Antonomia de Chapingo (Mexico)
UNCTAD	-	United Nations Conference on Trade and Development
UNDP	-	United Nations Development Programme
UNEP	-	United Nations Environmental Programme
UNESCO	-	United Nations Educational, Scientific and Cultural Organisation
UNIDO	-	United Nations Industrial Development Organisation
UNU/ INTECH	-	United Nations University - Institute for New Technologies
UPOV	-	International Union for the Protection of New Varieties
UPS	-	Uninterrupted Power Supply
USAID	-	United States Agency for International Development
VAD	-	Vitamin A Deficiency
WARDA	-	The Africa Rice Center
WTO	-	World Trade Organisation

CHAPTER 1

INTRODUCTION

1.1 Rationale

In today's increasingly competitive global environment, the crucial strategic variable for rapid and sustainable development is technology (Sharif, 1988; Freeman, 1992; Bigg et al, 1995; UNCTAD, 1999). The cumulative advancements in Science and Technology (S&T) in the past few decades have generated technologies that are transforming the basic structure of national economies and human societies. Described variously to highlight their inherent uniqueness, the "emerging", "new" and "revolutionary" technologies are underscoring another kind of indispensability of technology in development (Miles, 1997, p.65). Developing countries have not only to build capacities in these modern technologies, but also must mobilise and direct those capacities to address the critical socio-economic problems in their national contexts (Hassan, 2000, p.40). Biotechnology in particular is propounded to be the key revolutionary technology for developing countries given the potential for impact across many sectors including agriculture. The fundamental question is *how* to create the necessary capacity for the application and development of biotechnology to make the expected impact. The question of *how* is not only a challenge in the context of national development, but it is also an imperative in the approach to technology development studies.

In this regard, the question of how needs a comprehensive research within the relevant limits and scope of the issues pertaining to the nature of the technological changes and the potential impacts of biotechnology in the development process. For, biotechnology has demonstrated a new requirement for the approach to the application, development and management of S&T and as in the case of all the new technologies the problem of how to plan and build technological capacity has become an even greater challenge. Biotechnology poses its own challenges on account of its intrinsic characteristics and its strategic importance in the scheme of national development. This is because in relation to the natural endowments, it is the more relevant new technology for developing countries with relatively fewer requirements for active participation in global applications (Juma and Mugabe, 1997, pp.115-139). What is more, its cross-sectoral applications in agriculture, health and industry imply a multi-purpose utilisation of the capacity developed in that respect.

In the specific case of the developing countries, there is also the expectation of playing catch-up technologically. The Green Revolution and other major technological revolutions of the steam engine, printing, electrical and electronic technologies bypassed Africa in particular. In the previous technological revolutions there were probably no opportunities and no “significant determination, resolve or political will to chart one’s own future using technology as the means of development” (Sharif, 1988, p.195). Biotechnology in particular is a challenge for developing countries to make their mark on the global technological change and "catch up" with the rest of the world. African countries such as Ghana must therefore ensure that she participates in the biotechnology revolution (Wambugu, 2001).

But the precipitated question is how realistic is that proposition of "catching up" with the rest of the world. Developing countries' continued under-development rests on the fact that they have not been able to effectively incorporate technology into their development strategies and therefore have lagged behind. The technological gap has put many light-years between the developed and developing countries and continues to widen. How for example, African countries such as Ghana can close that gap and attain appreciable levels of socio-economic advancement, as has occurred in the newly industrialising countries, has remained at the centre of development debates. Apparently, there is not sufficient empirical work on providing a model for developing technological capacity in the specific context of developing countries. Naturally, the diversity of the contexts of developing countries makes it perhaps impossible to formulate one model for all developing countries. However, there are essential elements that can possibly be distilled from the experiences of the successful developing countries, which can provide a basis for formulating a general framework for building technological capacity in the specific context of developing countries.

Naturally, technological capacities must develop within the specific national context with its complexity of socio-cultural practices and economic realities. In agriculture for example, farmers' practices of selecting and saving seeds create an important stock of genetic resources for the country. In the application of biotechnology to improve crop production, the stock of genetic resource constitutes a vital basis. But there is the problem of the potential decrease in the stock of genetic resources as farmers adopt hybrid or modified seeds. The prevailing practices in crop production may offer benefits that must be enhanced in the application of modern technologies. The application of biotechnology in crop agriculture such as with the dissemination of hybrids can cause the erosion of indigenous varieties or landraces and deplete the national stock of genetic resources. However, the problem of the deleterious effects of modern technology usually surfaces when there is little planning of the technological development. For biotechnology in particular, planning is crucial given its potential effects on farming systems generally.

Indeed, the national capacity for biotechnology application has to be built over time within the framework of the national development plan and the building of technological capacity is a deliberate and planned occurrence (Vitta, 1997, pp.1471-1480). The approach for the capacity building process is important. It should be holistic and should address issues on both the supply and demand sides. This thesis therefore rests on the premise that the deliberate planning of building technological capacity in a holistic manner is a critical determinant of technological capacity in the developing country context and more particularly so in the efforts to play catch-up. Biotechnology is an opportunity for participation in a prevailing technological revolution. In this connection, research into the processes, mechanisms, and the nature of biotechnological capacity building will be a useful academic undertaking as well as policy research imperative.

1.2 Background

Ghana has enormous problems in food production. The problems are not peculiar to the country alone but are typical of most Sub-Saharan countries. It is projected that by year 2025 sub-Saharan Africa will experience a grain shortfall of nearly 90 million tons. The proviso however is that farmers maintain current cereal yields. Unfortunately, yields have been decreasing over the past 40 years (Thomson, 2001). In Sub-Saharan Africa about 70% of the population live primarily on and earn their livelihoods through agriculture. On the average, agriculture contributes about 35% of GDP, 70% of employment and 40% of export earnings (MOFA, 1999). The poor performance in agriculture thus affects almost the entire population. In this connection an obvious means of addressing the problems is the injection of S&T into agriculture. But in spite of the high dependence of the economy on agriculture, there is a low S &T input in the sector. For example, value addition in agriculture, contributes only about 20% to the total Gross Domestic Product (GDP) (MOFA, 1999).

Ghana typically reflects the high dependence on agriculture and low scientific inputs leading to a low agricultural productivity. About 57% of the country's land area is available for agriculture but less than half of that land area is put under cultivation (MOFA, 2001). The prevailing mode of farming is predominantly subsistence whose performance is generally dependent on biotic and abiotic factors. Only 0.2% of the area under cultivation is irrigated. (See table in Appendix 4 on land use in Ghana.) The low application of technology in crop production has led to a relatively low output in the sector and presented an enigma for policy-makers to grapple with.

Over the last ten years, agriculture's contribution to Ghana's GDP was over 40% (ISSER, 2000). The current government economic policy aims at reducing agriculture's high contribution to the GDP. However, the policy direction is not intended to reduce the value of agriculture in the total economic performance. Rather, it is to enhance its role in sustaining the population in relation to food security and improved nutritional status. The vision under the accelerated agricultural growth and development programme in the medium term (1997 - 2007) is to increase agricultural GDP from about US$2.9 billion to about US$5.5 billion within the context of an overall GDP of about US$15 billion. Though it implies a relative decline of agriculture's contribution to GDP from an average of 45% between 1991 and 1996 to an average of 37% between 1997 and 2007, in terms of value there is a substantial increase (MOFA, 1999, p.37). Naturally if the enhanced contribution of agriculture to the national economy must be achieved then technology application must be intensified. The intensification of technology application however can only be selectively done given the limitation of resources and need for prioritisation. In this regard the option is for the strategic adoption and development of generic technologies that have potential for impact even beyond the agriculture sector.

Underpinning the strategy to increase the GDP in the medium term is the drive to promote exports with non-traditional exports playing a major role. Indeed, all through the 1990s, the value of the non-traditional exports had been increasing annually. From a total value of US$62.5 million in 1991, it increased to a total of US$404.4 in 1999 with the agricultural component also increasing over the years as shown in Appendix 4.

Crops such as pineapples, mangoes, pawpaw, cottonseed, yam and vegetables have become export commodities with potential for larger export earnings in future. The problem however is that, the development of the non-traditional export sector is hampered by a lot of constraints some of which are due to the lack of the necessary scientific support for the achievement of the export targets (Frempong, et al, 2000). For example, crop pests and diseases have made it difficult for the producers of these export commodities to make maximum returns on their investments in not being able to meet quality standards on the international markets.

A similar problem exists in the food crop sub-sector in terms of production of staples. Even though the production of various food crops has seen some increases as shown in Appendix 4, these increases are slight and therefore the food situation remains problematic. The impact of the food situation has been hard on farmers earning marginally from their labours. As a socio-economic group, food crop farmers experience the highest incidence of poverty in Ghana. (Ghana Statistical Service, 2000) Providing a solution to the problems in food production is an important key to poverty alleviation, which is currently at the centre of Ghana's development planning (Ghana Government, 2001).

Indeed the general problem underlining crop agriculture derives from the limited scientific and technological application in the production process. Despite the importance of agriculture to economic growth, the needed public and private investments in S&T applications have not been enough to enhance the support base. The majority of farmers who are subsistence barely have enough resources to invest in S&T inputs. Thus crop production has not yet reached the appreciable levels and has suffered from low technological inputs. Taking the case of local staples such as maize, yam and cassava, the yields farmers obtain are generally less than half the achievable yields for the staples. Even for cocoa, which is the leading crop export earner, the farmers' yield is 0.39 metric tonnes per hectare whereas the achievable yield is 1.0 metric tonnes per hectare. (See Appendix 4.)

Achievable yields indicate "yields that have been achieved in isolated cases due to more effective extension and use of recommended technologies by farmers" (MOFA, 2001). The recommended technologies include inputs such as fertilizers, weedicides and pesticides. It implies that farmers on the whole have not been able to significantly apply these technological inputs to achieve the determined yield levels. The farmers' abilities to adopt these in their farming activities are limited by a number of factors including lack of proper knowledge and financial resources. For example, Ghana's annual fertilizer consumption is estimated at about 35,000 tonnes as against an annual requirement of some 400,000 tonnes (FAO, 1999). This consumption is one of the least in Africa - Ghana uses less than 10kg per hectare compared to countries such as Zimbabwe (53 kg per hectare) and Egypt (366 kg per hectare) (MOFA, 2000). One of the main reasons for Ghana's very low consumption of fertilizer is the relatively high price on the market. Analysis of the fertilizer-to-crop price ratio has shown that use of fertilizer has become less profitable over the years, as fertilizer prices increased much faster than crop prices (Gerner, et al, 1995). An obvious technological option is to increase fertiliser usage on the farms through appropriate interventionist mechanisms. But there are costs to this not only in terms of the economics, but also in terms of environmental sustainability.

Another technological option to improve crop production is to enhance the intrinsic trait of the crops to produce. In this connection, biotechnology provides the possible means of improving the crops' own traits for higher yields. Greater resistance to pests, resistance to specific environmental stresses such as drought and salinity and the reinforcement of genetic traits can be engineered into the crops to increase yields. Such biotechnology applications may result in savings against costs of fertilisers and chemicals in the long term. However, there has to be the biotechnological capacity to improve the crops in the first place. The question is whether Ghana is building the capacity for biotechnology application and how effective are the mechanisms for building that capacity.

Ghana has established a national agricultural research system (NARS) comprising the research institutes, universities, specialised agricultural institutions and other miscellaneous institutions. There is the Council for Scientific and Industrial Research, which has under it, seven agricultural research institutes including the Crops Research Institute, the Savanna Agricultural Research Institute and the Plant Genetic Resources Centre. In the public universities, there are the faculties of agriculture and science whose departments make important contributions to agricultural research and development (R&D). There are other research institutions under the Ministry of Food and Agriculture (MOFA) as well as post-secondary agricultural colleges. All these institutions in the NARS play important roles in the generation, adoption and transfer of agricultural technologies. In this connection, though biotechnology applications occur in the NARS, a number of questions arise. What types of research activities are going on and to what extent do the outputs of the NARS relate to the specific farming problems prevailing in the country. There are other equally important issues and questions such as what capacity actually exists for biotechnology, the nature of such capacity, the success stories and the factors for success, the failures, the constraints and the mitigating factors. These are all aspects of the problem relating to the lack of knowledge of Ghana's biotechnological capacity, which needs to be addressed.

The lack of effectiveness of the NARS in addressing some of the crucial problems facing local farmers seems to overshadow other important achievements the NARS has made. The critical issue is the effectiveness of the transfer of innovations from the NARS to the points of demands on the farm. There is a gap between the supply side of innovation and the demand side. It has led to a crisis of confidence in the establishments for scientific enterprise and more precisely for Research and Development. Currently, there are various discussions to restructure the core organisation for R&D - the Council for Scientific and Industrial Research. The organisational framework for R&D must facilitate the application of strategic technologies. Whilst it is hoped that improvement in the S&T organisational framework will improve effectiveness of the NARS, the crucial issue remains how to ensure effective transfer of innovations from the supply side of innovations to the demand side.

Besides, in the NARS itself, there are factors that are critical to their effectiveness. For example, the types of human resources available and the prospects for knowledge acquisition are important factors in the delivery of innovations. In the case of biotechnology, this becomes a critical factor given the continued expansion of the stock of knowledge. Also, what are the incentives and the factors that stimulate the application of knowledge in the generation of innovations? It is important to assess the conditions on the supply side of innovations to determine the options for amelioration.

Similarly, there are factors that are key to successful transfer of innovation to the demand side. For example the conditions of the potential users of the innovations – the farmers – and the ability of the users to obtain information about the available innovations are some of the issues that need to be understood. There are also other developmental issues that have gained increased importance in current development debates and need to be explored. For example the issues of gender as inhibitors (or catalysts) in the transfer process need to be understood to formulate the appropriate strategies for effectiveness. It is generally believed that men are more receptive to the extension of technologies than women. The application of biotechnology, if it must impact evenly across genders may therefore need new strategies for extending and communicating innovations to the users taking account of their gender differences. There is the need therefore to determine the nature of the gender issues and formulate strategies for overcoming them.

Another problem is the absence of a biotechnology policy to provide the necessary impetus for biotechnology development and application. The problem is not peculiar to biotechnology. Even in the case of the National Science and Technology Policy, it was not until 2000 that it was enacted (Ghana Government, 2000). A policy spells out definitive goals and objectives, outlines the intended course of action to achieve these goals and provides a framework in terms of organisation, regulation and timing for achieving these (Sharif, 1988; Vitta, 1990). The absence of a policy therefore denies the process of technological capacity building of an impetus and the necessary dynamism. There has been some research work in the past to draw attention to this problem (Essegbey, 1997). Yet not much has been done and it is still important to highlight the need for capacity building particularly with reference to current development trends in biotechnology and the issues that arise there from.

Another side of the problem relates to the increasing technological gap between where the prevailing national capacity in biotechnology and the state of the art international. For example in crop agriculture, what appears to be the ultimate in biotechnological applications is the development of transgenic or genetically modified (GM) crops. Currently, the total global area of GM crops was estimated to be reaching 50 million hectares by the end of 2001. It was more than a 10% year-on-year growth compared with 2000 (ISAAA, 2001). The transformation of crops to the appropriate transgenic varieties is becoming an established procedure for dealing with some of the key constraints in crop production. It provides the tool for singling out specific constraints such as susceptibility to pest infestation to address them. Some of Ghana's staples such as maize, tomato and rice have got transgenic varieties. But no transgenic crop has been developed in Ghana or has been transferred to Ghana. Cash crops such as cotton also have their transgenic varieties. In 1996, cotton engineered with the pest-resistant Bt gene was first introduced to the market in the U.S. Since then, over a dozen other crops of the transgenic varieties are being commercialised. The transgenic cotton gives a 10% more yield and needs less than 50% of the insecticide to protect the crop (Patlak, 2000). Even though the increasing gap in biotechnology development is a characteristic problem of developing countries, some African countries such as Kenya, Zimbabwe and Uganda are creating appreciable biotechnological capacities to close the gap. How these countries are doing it and what constitutes the best practice in Ghana's current socio-economic condition are questions that need to be answered to facilitate Ghana's biotechnological development.

But the point needs to be emphasised that; the introduction of transgenic crops or GMOs into Ghana's agriculture cannot be done without a critical analysis of the issues involved. In both parts of the developed and developing worlds, the diffusion of transgenic crops is creating controversies. There is a clear divide between the pessimistic opponents of biotechnology and the optimistic proponents. The lesson of the controversies is simply that biotechnology development goes with uncertainties, which cannot be overlooked. The question is whether Ghana is taking the necessary steps to put in place anticipatory policies to address this. Genetic engineering is the state of the art and Ghana must aspire to create capacity in that technology. However, the experiences of countries in various parts of the world show that there is need to formulate an appropriate framework to address the corollary issues.

Apart from the need to address issues of biosafety, there are issues relating to intellectual property and private sector investment in biotechnology applications. The crucial issue is the role of transnational corporations (TNCs) in the application and development of biotechnology – particularly with regards to the commercialisation of transgenic crops. TNC's business interests sometimes run counter to the interests of other stakeholders such as farmers and environmental activists. This creates problems in the diffusion of biotechnology products. The question of how to encourage TNCs' business in biotechnology applications requires realistic policy instruments to safeguard the interests of other stakeholders.

Indeed, there is no gainsaying the fact that, biotechnology has provided a resourceful tool for development world-wide. The question is whether Ghana is putting herself in good stead to exploit, utilise, apply and develop this generic tool particularly for crop production. It relates to the kind of technological capacity being built and the means by which this is being done. The attempt to provide a researched basis for addressing these problems is important also for the fact that, it constitutes important input into the discussions of technological development in the context of developing countries.

There have been a number of initiatives in biotechnology in Ghana's system of innovation, specifically in the Research and Development (R&D) institutions as well as in the institutions of higher learning (Acheampong, 2000). For example research institutes of the Council for Scientific and Industrial Research (C.S.I.R.) are applying biotechnology in addressing their institutional mandates in areas such as agriculture and health. Some of the relevant university departments and research institutes have also demonstrated the importance of biotechnology in their educational and research activities. In other sectors of the economy such as industry, biotechnology application is prevalent at almost all levels. R&D work to enhance food production on the various farms highlight some of the practical ways the application of biotechnology can be made directly relevant to the ordinary Ghanaian. For example researchers at the Crops Research Institute are working on improving traditional staples such as maize, cowpea and cassava. However, policy initiatives for biotechnology development as for example in crop agriculture have not moved in tandem with the activities on the ground and many of these activities fall short of synergy (Essegbey *et al*, 1999).

In this regard, there have been efforts to stimulate policy discussions on biotechnology and the issues that relate to its development. For example in 1998, the Institute of Biologists organised a symposium on Biotechnology Development in Ghana in Accra, highlighting issues of regulation and biosafety. In 1999, the Science and Technology Policy Research Institute (STEPRI) of the C.S.I.R. collaborated with the Graduate School of Environmental Studies (GSES) of the University of Strathclyde to initiate the Biotechnology Development Programme (Essegbey *et al*, 1999; Stokes *et al*, 2001). The programme had three main objectives namely:

- policy research to provide inputs for biotechnology policy formulation;
- capacity building to enhance institutional capacity through networking, linkages and sharing of resources, and
- Technology Assessment to develop a model for assessing technology appropriate for developing country context.

Perhaps the Biotechnology Development Programme was the most concerted effort aimed at stimulating policy initiative for a holistic development of biotechnology in Ghana in the sectors of agriculture and health. Its adoption of stakeholder participation as a methodological tool enabled issues to be raised for consideration in the development of biotechnology in the country. The programme highlighted the need to stimulate conceptual understanding of the issues that relate to the policies and the implementation processes, and in particular to attempt a model for holistic development of biotechnological capacity. What is most fundamental to these issues is how to develop biotechnological capacity and foster its integration into national development. Answering this question requires a comprehensive analysis of the issues from multi-dimensional perspectives.

This thesis therefore attempts such an analysis in full awareness of the complexity of the issues. The delimitation of the scope of the research to crop agriculture in Ghana and specifically to biotechnological capacity building is an attempt to reduce the extent of the complexity. But it is also an attempt to focus more on an area, which perhaps has the highest relevance to the lives of the people in the society, who ought to be at the centre of the efforts in biotechnological capacity building.

1.3 Statement of Research Problem

Agriculture output in Ghana compared to the developing countries such as Malaysia, Korea, South Africa and Brazil is very low. The marginalisation of policy for promotion and regulation of biotechnology has contributed to the poor performance of the crop sub-sector. There is no strategic framework for harnessing the potential of biotechnology for crop production. In this regard, the case of biotechnology in Ghana provides an empirical basis for addressing specific research questions:

- What is the nature and status of biotechnology in Ghana?
- What are the biotechnological activities going on in the country?
- How do the biotechnological activities relate to the national development goals?
- What are the gaps between what prevails in Ghana and the state of the art?
- What is the nature of demand for biotechnology applications?
- What country experience and best practice exist to inform the policy formulation process in Ghana?
- What are the policy options for developing an effective biotechnological capacity?

These questions are thematised against the backdrop of the challenges that confront the nation in integrating biotechnology in the development process. More particularly, the study aims at addressing the need to examine the overall S&T analytical framework for S&T planning and implementation with particular emphasis on biotechnology.

1.4 Objectives of the Study

The overall goal of the study is to contribute to understanding the dynamics of technological capacity building in a developing country context. In this connection, the research into biotechnological capacity building in Ghana is aimed at providing empirical analysis of the state of biotechnology, its application and its development. The specific objectives are to:

- assess the state of biotechnology in Ghana in terms of both supply and demand,
- analyse the trends in biotechnology development in Ghana,

- analyse the experiences of other countries in biotechnological capacity building to determine the best practice,
- analyse the prevailing gaps in Ghana's biotechnological capacity,
- generate policy options for biotechnology development in Ghana.

1.5 Organisation of Thesis

Chapter 1 gives the introduction. It gives the rationale and justification for the study, defines the problems, the objectives and the research questions addressed. In chapter 2, there is discussion of the concepts and theories under-girding the study. In this connection literature is reviewed pertaining to technological capacity building, the theories of innovation and biotechnology development. Chapter 3 deals with the methodology and the conceptual framework. It outlines the methods of data collection and analysis. Chapter 4 presents the assessment of the biotechnological capacity in Ghana from the supply side of innovation. It discusses the results of the survey of various R&D institutions and expertise in biotechnology application to crop production in Ghana. Chapter 5 contains the assessment of demand for biotechnology products in Ghana. Using a case study of farmers in the New Juaben District. Chapter 6 gives an overview of biotechnology development in Ghana, trends, issues and projection for the future. Chapter 7 presents the best practice of biotechnological capacity building with the comparative analysis of the experiences of selected developing countries. Chapter 8 gives the policy options for biotechnological capacity development focusing on the key policy areas including human resource development, intellectual property regime and the regulatory framework. Chapter 9 highlights the findings, theoretical reflections and the conclusions.

CHAPTER 2

BIOTECHNOLOGICAL CAPACITY BUILDING - A REVIEW OF THE LITERATURE

2.1 Introduction

This chapter reviews the relevant literature to create the conceptual and methodological foundation for the thesis. The concepts that inform the thesis are primarily those that relate to technology, its development, application and management and the building of technological capacity generally. The chapter reviews literature pertaining to biotechnology development. This is important because the way technology is conceptualised conditions the research methodological path pertaining to technology development (Khalil-Timamy, 2001). Fortunately a large body of literature abound that may collectively be put under the all-embracing theme of Technology and Development. The more recent works include those of Fransman (1986), Adei (1987), Freeman and Perez (1988), Lall (1992), Nelson (1993), Weiss (1993), Clark (1999) and Mytelka (2000). The main aim of this chapter is to establish as far as possible the unity in the diversity of the literature available and to indicate the areas of application in the approaches to technological capacity building in the developing country context of Ghana.

2.2 Technology

Before the works of neo-classical economists established the "technological" case, the classical economists broadly alluded to the importance of technology in economic growth. For example, both Marx and Ricardo had noted the value of technical change with the latter remarking that he "…who made the discovery of the machine, or who first usefully applied it, would enjoy an additional advantage, by making great profits for a time" (Ricardo, 1830, pp.378-379). However, the conceptualisation of productivity or growth was in terms of capital and labour combinations. Neo-classical economists such as Abramovitz and Solow however produced the seminal works to put value on the contribution of technology in the production process showing that about 80% in increased output could be attributed to technology (Abramovitz, 1956; Solow, 1956 and 1957).

If the very seminal works done in the 1950s brought technology prominently to the centre-stage of neo-classical economics, later works clarified the nature or role of technology in the production function (Denison, 1962; Samuelson, 1967; Mansfield, 1968). The later works of the 1960s and 1970s focused mainly on Research and Development in the processes of production in an effort to show the expansion of the stocks of knowledge that enhanced the role of technology (Mansfield, 1968; Griliches, 1984). Undoubtedly, these later works took their inspiration from earlier works regarding the genesis of innovation particularly those of Schumpeter. This body of literature has developed into what is generally referred to as the theories of innovation. The importance of this is that, they provide a theoretical framework for analysing the issues that deal with technology. As will be shown in the latter sections of the chapter, the evolution of the concepts in innovation and the broader area of Technology and Development have made it possible to extend the concepts not only across sectors but also across national contexts. In other words, whereas most of the empirical works were done in the industrial sector and in the advanced countries, the discussions of the consequential theories provide a framework for analysing technological trends in the developing countries. What currently is at issue is the extent of the generalisability of the concepts or framework for technological development, utilisation and management particularly in relation to the contextual differences of countries and societies. However, the limits on the extent of the application of the concepts are in the areas of consensus in the literature.

Firstly, what is clearly a consensus from the literature is the point that, the word "technology" carries much more than it does in the ordinary day to day usage of the word. From a disciplinary perspective, it carries certain fundamental conceptual connotations. For example, the ordinary dictionary definition of technology is simply that technology is the application of science. It is "the study and knowledge of the practical, especially the industrial use of scientific discoveries" (University of Cambridge, 1995, p.1495). The images conjured are those of the artefacts - machinery, equipment, tools, products, etc. Thus the ordinary meaning hardly goes beyond the superficial shown in the tangible technology. In the literature however, it is the conceptual connotations that provide insight to technology development in a given context.

Another almost consensual point in the literature relates to the relationship between science and technology. Science and technology may be conceived of as independent bodies. However, they are mutually beneficial bodies of knowledge, created by different processes of accumulation within distinctly different communities located in different institutional contexts (Falkner, 1994, pp. 425-458; Metcalfe, 1997, p.726). Science is academic with the legitimate output of additions to existing stocks of knowledge whereas technology is practical and the outputs are in their simplest forms, artefacts and tangible things. Technology draws on the outputs of science as well as feeds into science. In the modern context the flow between science and technology is becoming more and more intense.

Technology usually carries the implication of a change in the way in which we organise knowledge about productive techniques. There is what is commonly called "production technology" which usually refers to the knowledge and procedures used to "transform inputs derived from the natural environment into useful outputs in terms of goods and services" (Vitta, 1990, pp.1471-1480). However, the definition also extends to the "logistics and social relations of production including what is commonly referred to as consumption technology" (Vitta, 1990, pp.1471-1480).

Technology is also defined as "all elements of productive knowledge needed for the transformation of inputs into products, in the use of these, in the development and rendering of services, as well as in the generation of further productive knowledge. In this context, technology yields a determining influence on the economic and social advancement of societies"(Junta de Acuerdo de Cartegena, 1976).

The extended concept of technology suggests the need to adopt a holistic outlook on technology. The Economic Social Council for Asia and Pacific (ESCAP) in its

Technology Assessment Project conceived of technology as consisting of four main components namely:

- physical facilities or technoware
- human resources or humanware
- information system or inforware
- organisational framework or organoware.

From these definitional perspectives, the deeper undertones of technology surface. For example, beyond that piece of artefact are related systems and structures that must be understood for that piece of artefact to have meaning. The limitation of the concept however is in its own extensiveness. If for example, one talks about an ordinary technology such as pen, where does one set the limits? Apart from the factory where it is manufactured, there are the more or less supportive industries and services - chemicals, plastics, marketing, etc. - that have to be considered in the "pen technology". Drawing the circumference of the domain of the pen technology becomes somewhat difficult and it limits the extent to which the composite units can be analysed for failures and successes. Despite, the limitation, defining technology from multi-dimensional perspectives is a useful concept especially in undertaking a technology assessment.

This thesis therefore adopts as its bedrock the ESCAP concept of dis-aggregation of technology. The dis-aggregated concept is important because, technology used in the sense of "the means to satisfying the basic human needs of food, shelter and clothing based as it were on the skills of hand and eyes" is simply not sufficient in the modern context (Freeman and Soete, 1997, p.14). The expression technology, with its connotation of a more formal and systematic body of learning, only came into general use when the techniques of production reached a stage of complexity where these traditional methods no longer sufficed. This is an important development particularly in the modern context because then a clear distinction is made between the traditional "arts and craft" technology and the newer technologies, which are revolutionising the relationships between science and society (Freeman and Soete, p.15). More importantly, it establishes the need for countries to acknowledge technology as a strategic variable in the development process particularly in respect of the "revolutionary" technologies such as biotechnology.

2.3 Technological Capability and Capacity

There are certain fundamental concepts that are derivatives of the multi-dimensional notion of technology and which deepen the understanding of the technological development process. Here, two of such concepts are key to the thesis namely, technological capability and technological capacity. On the subject of technological capability building, a number of concepts have been propounded with unifying strands. For example, technological capability is considered to be multidimensional and it exists at the level of the enterprise, industry (or sector of the economy) and country (Adei, 1987; Nelson, 1993; Lall, 1993; Fransman, 1996; Weiss Jr. and Clark, 1999). The thesis addresses biotechnological capacity building at the national level and therefore this concept is highly relevant.

To Lall (1992), there is essentially the firm-level technological capability and there is the national level technological capability. The former consists of investment capability, production capability and linkage capability. The latter - national level technological capability - comprises the incentive and institutional systems that support technological activities. Lall's conceptualisation therefore places equal importance on the firm-level actors as well as the national actors in the process of technological capability building and this is similar to other conceptualisations.

Lall (1993) defines technological capabilities in industry as the "skills - technical, managerial and institutional - that allow productive enterprises to utilise equipment and technical information efficiently." Lall goes on to emphasise the institutional nature of such knowledge, which accumulates over time from the combined skills of the members of the institution. The implication of this is that enterprises and for that matter organisations, must undertake to build capabilities which enables the organisation to absorb and *build upon* (author's own emphasis) the knowledge that has to be utilised in production. He states that the successful transfer of a new technology to a developing country has thus to include a major element of capability building and that simply providing equipment and operating instructions, patents, designs or blueprints does not ensure that the technology will be properly used. These 'embodied' elements of a technology have to be accompanied by a number of 'tacit' elements, which have to be taught and learned (Lall, 1993, p.721). It is an important concept because the application of biotechnology in R&D institutions is successful only to the extent that there is capability. The scientists must have the knowledge in context. Girvan's concept of technological capability is also important (Girvan, 1981). It defines technological capability as the ability to identify the most relevant technology for a particular purpose, to acquire it on the best possible terms, and once acquired to assimilate the technology internally. It also includes the ability to modify the required technology so as to adapt it to the specific circumstances of the user. Ultimately, it includes the ability to "create innovations internally as well as to market them commercially". In the delimited scope of this thesis, Girvan's notion of technological capability precipitates some of the stated research questions such as what types of biotechnology applications are going on in the R&D institutions and what kinds of expertise exists for those applications? Thus technological capability refers to the ability to do certain things. To be precise, it refers to skills.

Two main types of skills have been identified namely the static skills and the dynamic skills (Farell, 1979, pp.234-281). The static skills are the kinds of knowledge that enables a person to carry out routine tasks and functions successfully. The person with the dynamic skills understands the scientific principles governing the work and is capable of improving, modifying or changing the piece of machine, equipment, technique or process he or she may be working with to achieve results. According to Farrell (1979), every industry needs "critical skills" that, are the subset of both the static and the dynamic which ensure that the industry performs efficiently. People with skills and technical know-how are indispensable to the efficient running of modern industries. At the firm level technological capability will be reflected in the ability to undertake the functional activities, such as planning, production, maintenance, and marketing, that go into the successful running of a factory or a firm, to identify problems and to design solutions (Adei, 1987, p.11).

Another core concept, which informs the research and reinforces the notion of dynamism of skills, is the Bell and Pavitt approach based on technological accumulation (Bell and Pavitt, 1993). The concept brings into focus the role of learning in creating capability. It provides a scheme for accumulation of technological capability by distinguishing between the two stocks of resources that come into play namely production capacity, which yields industrial output and technological capability, which yields technical change. Bell and Pavitt (1993) underscore the role of learning in technological capability building. Learning should lead or yield technological capability, which should bring about technical change, which in turn, should lead to production capacity and then to industrial output. Thus, the specific areas in the process where policies should focus are those that relate to learning (e.g. education, training and skill-formation activities).

All these are concepts that are pertinent to the analysis of the capability for biotechnology development. They are concepts that provide the framework in the attempt to answer the fundamental questions pertaining to biotechnology development and application in the developing country context (Fransman, 1991). In the first place, are there skills that are not only static but also dynamic particularly in the centres of knowledge such as the universities and the R&D institutions? Are they adequate quantitatively and qualitatively? In the various biotechnology institutions and the formal educational system, what are the strategies for capability building? Is there a build-on process in capability in the institutions where biotechnology is applied?

It is necessary at this point to make a distinction between technological capacity and technological capability since generally there seems to be some consistency in the use of the terms in the literature. Capability normally refers to skills (Farell, 1979; Girvan, 1981; Adei, 1987). However:

> "Technological capacity is the sum total of people with the requisite skills, the stock of technical knowledge for them to draw upon, the tools and instruments for them to work with, and the institutional framework necessary for realising company or national objectives" (Adei, 1987).

In Bell and Pavitts' concept of technological accumulation, reference is made to production capacity and stocks of resources. Adei (1987) explicitly states that capacity goes beyond skills to include the other key aspects of technology namely the physical facilities, informational system and the organisational framework. The term "capacity" then is the totality of the domain within which the "capability" has to function. There really is no ambiguity in the use of "capability" and "capacity" except that quite often writers assume that the readers know what is meant and that may not necessarily be the case. So, putting it colloquially, capacity is the world in which capability has its being.

Part of the literature also introduces a systemic perspective to technological development. Freeman and Perez (1988) explain how particulate technologies of the firms in a given country could be conceived as inter-connecting to form technology systems and how these in turn link up in techno-economic paradigms. The proposition is therefore to develop techno-economic paradigms and not merely indigenous technological capability (ITC) at the firm level. Fransman's (1986) notion of technological mapping in finding the aggregate ITC is also instructive based as it were, on relating economic systems to biological systems. The micro economic systems are related to each other much in the same way that individual cells of an organism relate to each other and to their environment. It is important therefore that in analysis of a country's technological capability, attention be focused on the unit actors in the system.

The systemic approach provides a basis for postulations in relation to policy, which is one of the areas explored in this thesis. The importance of a policy framework for capacity building is captured in the Weiss Jnr. Model (Weiss, Jnr, 1993). He identifies six critical aspects of scientific and technological development including physical and social infrastructure, the productive sector and technology policy. He observes a two-stage development process and explains that in the second stage, linkages develop between supply and demand. Some of the linkages are automatic in the market economy whereas others require specific policy instigation. Weiss Jnr's Model provides an important base for this thesis in the sense that, the emphasis on a holistic approach to capacity building envisages a straddling of both the supply and demand sides of biotechnology innovations.

Indeed, the major critique against the conceptualisation of technological capacity as found in the literature is over-emphasis on the supply side of innovation. Most of the writers on technology development focus mainly on the supply side and consequently neglect the demand side implications. However, it is important that even at the inception of any given technological development effort, the demand component must receive the required attention in the same manner as the supply to prevent the failure of the technology. Technological capacity in the national context must be conceptualised as cutting across the supply and demand sides of innovation. In this regard, the definition of technological capacity building envisaged in this thesis is that:

> "It is the process of increasing the sum total of people with skills, the stock of technical knowledge and information for them to draw upon, the equipment and facilities for them to work with, the institutional framework to achieve set objectives and the conditions to foster and meet demands for technological outputs."

The systemic approach also envisages the extent to which some of the concepts in the technology development literature are applicable in the contexts of developing countries. This thesis notes the preponderance of the studies done on innovations in the developed economies, especially in industry. Current compilations of such literature virtually exclude studies done in the African contexts (Edquist and McKelvey, 2000). For the fact that there are contextual peculiarities, there is need to initiate such studies in the African contexts to elucidate the concepts of technology development. In recent years, there have been some efforts in this regard through the initiatives of the African Technology Policy Studies Network (ATPS). However, much more needs to be done to address the gaps in the literature on African technology development. This thesis hopes to make a contribution in that direction.

2.4 Biotechnology Development and Trends

Over the centuries, farmers have indulged in the simple practice of selecting seeds for planting in the next planting season. The practice has led to enormous improvements in the types of seeds or planting materials available to the farmer. A classic illustration is found in the difference between the teosinte ancestor of corn and modern corn, which is about fifty times the size of the teosinte ancestor (Pueppke, 2001, pp. 1233-1245). That was the beginning of traditional biotechnology. From the simple practice of selecting seeds, man developed the techniques of grafting as far back as 1000 B.C. (Pueppke, 2001, pp.1233-1245) Hybridisation was the next step in the progression of traditional biotechnology and it involved the crossing of genetically distinct parents with contrasting traits to produce a hybrid offspring that combines desirable characteristics from each parent. In it crude form, it is also a fairly old practice dating back to the Assyrians and Babylonians (Pueppke, 2001, pp. 1233-1245).

Scientists have been improving plants for millennia through various techniques of moving genes and combining genomes. These manipulations have created a tremendous variety of new plant forms tailored to the needs of the society. However with the development of modern biotechnology, scientists have an immense new knowledge and vastly greater options in the form of tools for moving genes and genomes around. It is possible to produce new plant cultivars with a precision and scope unimaginable just a few decades ago (Walgate, 1990; Weiss and Brayman, 1992; Pueppke, 2001). However, biotechnology must be held to the same standards of good science that have been applied to other techniques and in this respect, the concept of biosafety arises. It is important at this point to clarify the distinction between traditional biotechnology and modern biotechnology in relation to the scope of the thesis.

There are several definitions for biotechnology. However, in the broadest sense, biotechnology refers to the techniques involving the use of living organisms, or the parts of living organisms, as a means of production (UNEP, 1992; Avramovic, 1996; Cohen, 1994). The following definitions are some used in the literature:

- "The application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services" (OECD, 1982).
- "Any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop micro-organisms for specific uses" (US OTA, 1991).
- "A variety of techniques involving living organisms as a means of production" (Avramovic, 1996).
- It "includes any technique that uses living organisms, or substances from organisms, to make or modify a product, to improve plants or animals, or to develop micro-organisms for specific uses" (Cohen, 1995).
- " The application of indigenous and or scientific knowledge to the management of (parts of) micro-organisms, or of cells and tissues of higher organisms, so that these supply goods and services of use to human beings" (Bunders, et al, 1996).

Perhaps the differences in the various definitions have to do with the contexts and the authors' preferences for particular nuances. Nevertheless, they all illustrate the expansiveness of biotechnology. In the Convention on Biological Diversity (CBD), biotechnology is also defined as:

> "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use."

The CBD is a result of serious international deliberations initiated under the auspices of the United Nations, beginning in 1988 and continuing until 1992 when the Convention was signed. Thus the socio-cultural discourses were quite comprehensive before the adoption of the CBD along with its definition of biotechnology. It may therefore appear to have captured as much of the quintessential detail as necessary. Indeed most other definitions come out as derivative versions of the CBD's. What is important for this thesis however is the need to situate biotechnology within the research context. It is a technology with the same attributes of multi-dimensions as other technologies. Yet its uniqueness - for example as a generic technology - imposes more than ordinary complexity in its situation. It implies that the mechanisms for capacity building must therefore be specific and apropos to the socio-economic context.

Biotechnology is usually classified broadly into traditional biotechnology and modern biotechnology. Traditional biotechnology is that spectrum of techniques that relate to the traditional production systems involving the use of living organisms to make products. Bread, yoghurt, cheese, beer and all the food products that are made through fermentation are examples of products of traditional biotechnology. In Ghana, the traditional food "kenkey" made from fermented corn dough, the drink "pito" made from sorghum and palm wine produced from the palm tree. These are also the examples of products of traditional biotechnology of the Ghanaian society.

In all human societies, cultural practices have generated techniques that used living organisms to make products one way or the other. Bunders *et al* (1996) also like Pueppke (2001) emphasises the ancient origins of biotechnology development and defines it from the socio-cultural perspectives. What Bunders *et al* have succeeded in doing from their perspective is to reinforce the cultural dimension of biotechnology which is something that is buried in most other definitions including the CBD's and its derivatives. It is important for the main reason that it provides a locus for biotechnology development within the country development context in terms of the skills, techniques, products, facilities, institutions and markets. It facilitates the analysis for determining the lacunae in development with reference to other countries. The distinction made between the traditional biotechnology and the modern biotechnology can therefore be a useful accessory in the technology assessment process and in defining the culture-specific biotechnological innovation that one expects from the NIS. Besides traditional biotechnology is not only made up of the relatively primitive techniques of the fermentation of traditional foods. In agriculture biotechnology, the techniques of hybridisation involving cross-pollination fall within traditional biotechnology. But these are still important techniques in the context of crop agricultural innovations in developing countries.

Modern biotechnology evolved with investigation into the biochemical and molecular constituents of the hereditary materials in living things. An important breakthrough was when in 1953, Watson and Crick made the discovery of the structure of deoxyribonucleic acid (DNA) at Cambridge University. The DNA was shown to be the hereditary material that formed the basis of all living things ranging from the Aspergillus fungus to zebra. Four chemicals known as bases - adenine (A), cytosine C), thymine (T) and guanine (G) - are linked in specific sequences to code for specific instructions in the DNA for the regulation and production of a particular protein (Hawkins, 1996). There are distinct portions of the DNA coding for specific information in the organism. These portions are the genes and are critical to determining the type, constitution and behaviour of all living organisms. A single molecule of the DNA contains several thousands of genes found in chromosomes in the cells of the living organisms. For example a bacterium has one DNA chromosome that contains about 5,000 genes. A single plant may contain over 100,000 genes. The human being has about 300,000 coding for the myriad of traits that determine his or her form, sex and behaviour (Hawkins, 1996). The importance of understanding the nature and functions of genes is simply that, man could devise techniques to change, or more to the point, engineer - the genetic make-up of a particular organism for a pre-determined trait with regard to structure and or behaviour. It is even becoming more precise with the development of genomics and bioinformatics.

The progression of biotechnology on its technological trajectory after Watson and Crick's discovery proceeded with three major developments of technology applications namely:

- Recombinant DNA technology - techniques that enable the manipulation of the DNA;
- Monoclonal antibody (MAB) production - techniques used for the detection and production of specific proteins or antibodies; and
- cell and tissue culture - techniques that make it possible for rapid *in vitro* propagation of living organisms modified or non-modified (Persley, 1990, p.3).

Recombinant DNA technology enables the joining of genes from the same or different sources. This was made possible with the discovery of restriction enzymes. These are enzymes that split DNA at specific sites. Hundreds of these enzymes have been identified and are being used to alter the genetic constitutions of organisms. This is the basis of genetic engineering, which produces living modified organisms (LMOs) or genetically modified organisms (GMOs) with the latter being the more commonly used term.

MAB technology involves the identification and production of antibodies. These are proteins that bind onto specific proteins. Antibody-producing cells are fused with myeloma or cancerous cells. The resulting hybridoma cells from the fusion have the properties to produce the specific antibodies as well as the propensity for continous self-multiplication as in cancer. Being essentially clonal, the fused cells produce basically the same protein substances called monoclonal antibodies. MABs have become an important tool for production of a number of biological products including diagnostics for use in human and animal health as well as in crop agriculture (Persley, 1990).

Another technique, which enhanced the development of biotechnology, is tissue culture. The cell or tissue of a given living organism contains the full complement of hereditary material of the organism in terms of the genes located on the chromosomes in the nucleus of the cell. The genetic material enables the cell or tissue to have the full complement of information necessary for the development of the organism. It implies that if any of these cells should be placed in the appropriate medium and stimulated to grow, the whole of that specific organism should be produced. Cell or tissue culture is the production of an organism from its cells or tissue through the provision of the appropriate growth medium.

Developments over the years have made modern biotechnology a generic tool, applicable in several disciplines, e.g. virology, pathology, parasitology, immunology, pharmacology, embryology, citology and plant breeding. Apart from the cross-disciplinary nature, it is also a cross-sectorial technology underpinning developments in agriculture, industry, health and other sectors of the economy. In fact the term "biotechnology" is often used in terms of the applications of modern biotechnology. In this study, biotechnology will not be exclusively used as referring to the techniques relating to the applications at the cell or gene level and in crop agriculture. This is because, given the locus of biotechnology in Ghana's developmental context, much will be lost in imposing such exclusivity. More importantly, given the focus on crop agriculture, the study aims at highlighting the capacities that has been created on both the demand and supply sides of innovation.

Surmising on the new possibilities on the horizon with genetic modification - or more precisely, genetic engineering - Patlak (2000) noted that the possibilities are many and the number of bioengineered plants is likely to grow enormously in the new century. This has actually happened and the total acreage of bio-engineered or transgenic plants currently exceeds 50 million hectares (ISAAA, 2001). Between 1996 and 1997 alone, the acreage in industrial countries planted with bioengineered crops increased nearly 20-fold. Plant bioengineers are aiming to produce crops with salt-tolerant and drought-resistant traits. There are plans to bioengineer plants that produce specific compounds such as industrial oils, plastics, enzymes, drugs and vaccines. Some of these products such as the plastics, which normally are not biodegradable would have been produced to degrade over time. The vision painted here brings to the fore a point that has encumbered biotechnology development more than the other emerging technologies namely information technology and material science. It is that of genetic engineering creating new life-forms that pose a threat to life and the environment. The so-called Frankenstein foods are in particular the worst scenario projections for genetic engineering (Walgate, 1990; Teitel and Wilson, 2001). These projections form the basis for the concept of biosafety.

On account of the vision projected for genetic engineering, there is what may well be described as the ideological divide between the Optimists and the Pessimists. The optimists in the extreme are idealistic proponents of biotechnology as a panacea to all human dysfunction. The point needs to be made that quite often the term biotechnology is used in the same sense as genetic engineering. This is misleading since genetic engineering is only one of the techniques in the spectrum of technologies of biotechnology. This thesis adopts the broad definition of biotechnology and does not equate it to genetic engineering. The pessimists are in what appears to be a hysterical opposition to the technology seeing nothing good but evil in biotechnology. The opposition is however valid and important given the uncertainties surrounding the applications of genetic engineering. There are various types of risks in genetic engineering applications ranging from food products causing allergies in consumers to impacts on other non-target organisms (Walgate, 1990). The issue of biosafety, which evolved along with biotechnology advancement, must therefore attract the needed attention.

What the Optimist-Pessimist divide brings to the discourse is the need for balance in assessing biotechnology and a dispassionate appraisal of what is possible, feasible and vital within the country context. Too much of the dreams people had about the technology had come to naught. In fact, no technology in modern times has generated so great an expectation from investors, yet produced so great a disappointment as biotechnology. For example, of the over 1250 "new" biotechnology companies established since 1980, only handfuls are profitable at present (Humphrey, 1996, pp.321-332).

Nevertheless, some very concrete achievements have been made in the application of biotechnology to socio-economic problems. For example, rice is the staple food for over two billion people world-wide. It has been nutritionally improved through genetic engineering. The traditional rice lacks vitamin A and it is low on iron. Vitamin A deficiency (VAD) is the leading cause of xeropthalmia (childhood blindness), which affects about 400 million children all over the world (Morrisey, 1999, pp.79-81). At the Swiss Institute for Plant Sciences, scientists transferred into the rice genome, two genes from the daffodil family (Narcissus) responsible for producing beta-carotene. The scientists added a third gene from the bacterium *Erwina uredovora* (Morrisey, 1999, pp. 79-81).

The GM rice however highlights some of the issues with biotechnology with respect to intellectual property rights, prioritisation of needs in the developing country context and resource allocation. The set of technologies for the process of the genetic engineering of the golden rice was under proprietary ownership of organisations in the developed countries. Secondly the issue of whether the genetic engineering of rice to contain vitamin A should take precedence over its genetic engineering to contain higher levels of protein given the abundance of vitamin A in other sources such as palm oil is open to debate. Thirdly, in a process of the decision-making in allocating the amount for the genetic engineering process one wonders whether inputs have come from the developing countries where the rice is intended.

Given the potentials for biotechnology, developing countries have many reasons to consider practical applications of biotechnology consistent with being able to maintain a strong conventional research base and the ability to develop their scientific capacity (Cohen, 1994; Falconi 1999). But for countries to participate in the global biotechnology evolution, national research organisations need to incorporate basic capabilities and tools of modern biotechnology into productive processes. This is particularly important for agriculture, which in developing countries constitute the largest and most important sector of the economy. In Ghana for example, real GDP contributions by agriculture is about 40% and larger than that of any sector of the economy (ISSER, 2000). However in doing this, developing countries must match biotechnology development and applications to national needs and priorities.

This thesis examines the extent to which Ghana is exploiting or creating the conditions to exploit the potentials of biotechnology. Developing countries have aspirations for rapid economic growth. But that cannot be achieved without having experienced significant technological development. Technological development involves the development of among other things, institutions and organisations and physical facilities. Altogether they constitute a country's technological infrastructure. In this connection, the pertinent question is what really are the priorities and in what order and by what weight? How are they to be built? This is critical because as Evenson and Westphal stated, "the organisations are those where the scientific and technical competence of significant numbers of people are combined to achieve the advantages of specialisation and exchange. Such organisations may be private or public; they may exist as separate bodies or as constituent elements of larger entities. In them resides a substantial share of any society's accumulated stock of technological investment" (Evenson and Westphal, 1994).

New institutions or organisations are also evolving along with biotechnology development. Apart from the immense potential for plant transformation, modern biotechnology has expanded the confines of the agricultural system. Currently, in the advanced formal system, gene flow originates mainly from gene banks providing farmers, breeders and scientists with germplasm collected from farmers' field. The gene banks are therefore an important extension of the agricultural system (Pham and Hintum, 2000). There is also the need for amendment and revision of institutional arrangements in areas such as intellectual property and private investment. The development of biotechnology has thus brought about a need for institutional innovations. It is therefore critical to address effectively the processes involved in technological capacity building pertaining to the institutional and other components including technical facilities, informational facilities, human resources and organisational framework.

2.5 Theories of Innovation and Biotechnology

Biotechnology as a genetic tool has created the potential for innovations in diverse ways. The conventional literature as encapsulated in Schumpeter's model of economic development envisages innovation mainly as an invention with an implied linear character originating from a scientific institution and flowing through a simple pipeline to the downstream end. However, the notion of innovation has expanded from the linear model to a systemic concept and with the further conceptualisation that innovation is "the result of a complex interaction between various actors and institutions" (OECD, 1997; Mytelka and Oyelaran-Oyeyinka, 2001). Currently there is a growing attention in the development literature to innovation studies due in part to the increasing empirical perception of the importance of technological factors in the competitiveness and growth of nations (Dosi, 1998).

Bearing in mind the complexity of innovations generally, five possible forms of innovation are fairly discernible. The classification is sufficiently broad to cover the main types of technologies, which could be introduced during the biotechnology revolution:

- An innovation may involve the introduction of a new good or quality of good (production innovation);
- It may involve a new method of production (process innovation);
- Innovative producers may open a new market for existing goods (product innovation);
- An innovation may involve discovering a new source of supply of raw materials;
- It may involve the setting up of a new business organisation or improved handling of materials by existing businesses (Marks, *et al*, 1992).

An important development in the theories of innovation is the application of the systemic concept within the national context and the attempt to analyse innovations within the NIS. The NIS is defined as the "network of economic agents together with the institutions and policies that influence their innovative behaviour and performance" (Lundvall, 1992; Edquist, 1999; Clark, 2001). The NIS is the key driver of innovations and the innovations come with identifiable actors or stakeholders playing specific roles and functions in the innovation process (Johnson and Lundvall, 2002). It is important to understand the roles of the actors, their relationship and their interactions in order to envisage the vital policy initiatives that can facilitate capacity building and innovation for development. More importantly, the system approach highlights the significance of the national context for innovation and therefore the need for developing countries to situate their policy initiatives in context. The NIS concept also emphasises the notion of indigenisation of innovations. Biotechnology as a set of techniques needs to be adapted into the national context and ensure its applicability.

In the restricted Schumpeterian model of innovations, one can only expect innovations to come from the frontiers of scientific knowledge in the developed countries, especially with reference to an emerging technology such as biotechnology. In the linear model of innovation, the innovation process begins from the research stage and goes to the development stage, then to the production stage and finally the marketing stage. There is no recognition of the need for and the reality of feedback. With the systemic approach, which is partially captured in the chain-linked model of innovation, the research and development processes are linked to the production and market stages with flow of information among the stages. In the broader conceptualisation of the NIS, it is logical to expect innovations even in the developing country contexts. Thus it lends validity to the question of what innovations are there in Ghana's NIS with respect to biotechnology and what national strategies can stimulate innovations supply and demand. The concept of NIS directs the attention of policy makers to possible systemic failures, which may impede the innovation performance (OECD, 1997, p.41). Consequently, policies go beyond the simple goal of addressing market failures to aim at a holistic correction of the systemic dysfunction.

Naturally, there are corresponding demand-side effects for these innovations. In agriculture and in industry R&D on plants can supply new products such as pharmaceuticals, soaps and detergents. Mark et al (1992) concludes that biotechnologies can be "product or process innovations" and as such involve technological change. The important thing for public policy consideration, is that, the process of technological change may require developing countries to adapt their economic, governmental and social institutions to successfully introduce the new technology. This in itself calls for innovativeness. Mark et al (1992) note that the process is unlikely to be instantaneous and the impacts of biotechnology are likely to be both wide and far-reaching. Many existing and new products both within agriculture and in other sectors of the economy will be affected. There may be negative effects as well as beneficial effects. “By anticipating the impacts of biotechnology on the agricultural sectors of developing economies and highlighting key areas of concern for policy-makers, attempts can be made to mitigate major negative effects” (Marks, *et al*, 1992, p.29). Clark (2002) also proposes a cautious approach in public policy analysis and decision making “with as much dispassion and objectivity as possible”, suggesting that governments must establish new initiatives, capabilities and institutions that can have “a profound effect on legitimacy at a more fundamental level” (Clark, 2001).

Flowing from the postulations of supply of and demand for innovations is the issue of *analysis* of technological capabilities, which in the literature “appears to lack coherence” (James and Romijn, 1997, p.189). The lack of coherence is only to be expected given the tension between the need to quantify and the need to qualify the stipulated variables. Naturally, the tension exists in this study and even as the thesis makes effort to be guided by the illumination of the available literature, it has to be stated that it is a difficult task.

For example James and Romijn (1997) made the point that, the pressure for technological efforts emanates from the environment within which economic activities take place. There is an interaction of factors, which creates such environment. Such factors include the market structure, the rate of change of the international technological frontier, regulation of foreign trade, government investments in a supportive science and technology infrastructure through public R&D and technical education. In addition, "internal factors of enterprises in terms of ownership, nature of technology employed, attitudinal and personal factors are elements that affect and or induce technological capability building" (James and Romijn, 1997).

The crucial point here is the fact that there are a multiplicity of variables that interact to generate technological capability and in fact technological capacity. In different contexts, different sets of variables will be important. What one may do in any analytical endeavour is to identify those sets of variables that are critical. It is also of essence that James and Romijn (1997) mentioned government policies as determinants of, as it were, innovations. It accentuates the tension in the quantitative analysis of the technological effort vis-a-vis the qualitative. The question is how can government policies in terms of their contents be quantified? Yet these and other non-quantifiable variables have to be accounted for in the analysis.

As James and Romijn (1997) noted, at the country level, econometric analysis attempting to explain the emergence of capabilities have relied on crude proxy measures which bear little or no relation to what has been learned at the firm level. In other cases, 'input' measures such as R&D expenditure, number of scientists and education levels, have been used as proxies for capability, "when in fact they should be used instead as explanatory variables". Yet other studies have opted for impact measures in terms of productivity even though productivity increases can be taken as "evidence of accumulated technical knowledge only if other sources of improvement that have nothing to do with capability building - such as increased capacity utilisation or straightforward investment in more efficient technology - can be ruled out, which is usually not the case" (James and Romijn, 1997). The point simply is that the attempt to analyse technological capacity is not an exact science and can only be at best illustrative of basic concepts.

Since there are known to be numerous dimensions of technological capability (Lall, 1992), no single indicator is sufficient to encompass the measurement of all of them. Moreover, capabilities tend to be idiosyncratic and specific to countries evolved as there are from the "complex interplay of a country's history, economic policies, institutional environment and resource endowments." No simple quantitative measure can hope to capture the subtle differences in competitive advantage that emanates from such specificities.

James and Romijn (1997) hypothesise that variations in the degree of technological complexity can be explained by three kinds of variables, namely those that influence the demand side of the economy, those that bear on supply factors and those that reflect government policy towards the sector. On the demand-side, the key variable is the market size and in the empirical analysis, the size of the domestic market is used to capture the demand-side influence on technological complexity. It is measured in terms of the total GDP as well as the decomposition of the total into population and GDP per capita.

Measures of 'human capital' such as enrolments in education of different kinds and levels, government expenditure on education and the number of scientists and engineers usually capture the supply-side variable. Much as these efforts to capture the crux of technological state are well-directed, the limitations cannot be over-emphasised. For example, GDP per capita is simply deficient in reflecting a national situation whether in terms of development (which used to be what was the case in the 1950s and the '60s) or as a variable in technological capacity measure. An oil exporting country such as Brunei may have a higher GDP per capita than the highly indebted poor Ghana. Brunei has a population of only 300,000 and has a GDP per capita of US$ 17,868 in purchasing power parity whereas Ghana has a population of 18.9 million and a GDP per capita of US$1,881. However, the latter is more technologically advanced with regard to the complexity of its industrial activities. There are no indicators on which to make a categorical statement on which country is more technologically advanced. For example, using the Technology Achievement Index (TAI) of the UNDP, Ghana is classified as a marginalized country with a TAI of 0.139. That of Brunei is not given but for some of the variables going into the index e.g. Internet hosts and electricity consumption, Brunei has higher scores and therefore it is more advanced than Ghana. However, Ghana has higher scores for export of high and medium technology exports and mean years of schooling and therefore it is more advanced by these criteria. Definitely, the proposed framework for analysis easily belies the complexity of the task at hand. What is more, the policy variables would include the explicit Science and Technology policy as well as the implicit policies of national development and the sectoral policies. In practice these are extremely difficult to quantify. These analytical frameworks can however be explored with the proviso that apart from introducing corrective instruments, qualitative techniques are used to minimise the limitations.

Again the need to address supply and demand contents in the technological effort is alluded to in other parts of the literature. Wagner (1998) states that researchers and business people are becoming increasingly aware that the economic strides fostered by technological innovation require not only a scientific base, but also its transfer to the marketplace. At its simplest level, technological innovation can be thought of as a function of science "push" and market "pull". The real challenge however lies in integrating the efforts of science and commerce. Girafalco (1991) has identified a number of factors that impact on technological innovation. These include knowledge and skill base, the inherent possibilities of a technology, the existence of markets, the attitudes of a country's populace toward technology and the value placed on it. Others are the availability of physical resources, macroeconomic conditions, institutional structures that support research and development (R&D), national initiatives, political stability, government regulations relevant to scientific endeavours and commercialisation and the intensity of global competition in the development of a technology. (Girafalco, 1991)

One of the major constraints for developing countries is access to the state-of-the-art biotechnology, or more precisely, the new knowledge that is being generated. As Cooper

(1994) and others have elucidated, knowledge has many characteristics of public good. Once knowledge becomes available it can be used relatively easily though usually not without cost by others who did not originally create it. The creation of knowledge still has benefits in terms of returns on investments. But before returns from knowledge can be appropriated the knowledge itself must first be created and when created, the owners of the knowledge must take the necessary steps to secure their 'super-normal' profits. Possessing the 'core knowledge' underlying a product innovation for which there is adequate market demand is not sufficient condition for reaping all the rent that accrues from the innovation. This point has important implications for biotechnology.

For example, for products produced by recombinant DNA techniques, core knowledge might involve the ability to clone a gene for a particular protein or enzyme and express it in a host micro-organism (e.g. bacteria, yeast and fungi). However, this core knowledge is usually not sufficient to turn the output into a commercially viable product. Complementary manufacturing knowledge is required to transform the laboratory processes into a viable manufacturing operation. This transformation involves scale-up and development of efficient techniques for processing, recovery, and purification, all of which are likely to differ significantly from laboratory processes from which the core knowledge was initially derived. Apart from this, additional complementary assets are required. Evidently, the business of reaping rent from innovation involves far more than possessing the core knowledge. This brings to the fore the point about creating capacity as a whole rather than in parts in developing countries. The business sector needs the same kind of sensitivity to the potentials of biotechnology as the policy-maker and as the scientists that supply the innovations.

This point is well illustrated by the developments of the biotechnology companies. For example, apart from Monsanto creating linkages with researchers at the frontiers of biotechnology in the universities, it acquired various complementary assets through purchases of some companies and formed its own Hybritech Seed International. In Ghana, the question is whether there are enterprises that have caught the vision of what can be done with biotechnology whether at the small scale or large scale. Meaning that such companies are not only linking up with the centres of knowledge but are networking with other enterprises.

The point about creating extensive linkages also relates to agricultural policy formulation generally (Weiss, 1993). Diffusion theory has it that the rate of diffusion of a given technology in agriculture is determined by three main factors namely the proportion of adopters, the cost and the benefit from the technology. Diffusion models relate to the evaluation and adoption of a well-specified technology by individual producers operating in relatively homogeneous production conditions. The classic statements of the diffusion model are given by Griliches (1957) for agriculture and by Mansfield (1961) for industry. What they underscore is the role of policy in facilitating the diffusion process. In the developing country setting, diffusion of innovations is peculiarly constrained by several socio-economic and cultural factors (Evenson and Westphal, 1994, p.12). The agricultural policy initiatives must isolate these factors and address them. Likewise other relevant sectorial policies such as the S&T, industrial and economic policies should contribute to building capacity on the demand side in the same manner as the supply side.

The effective building of capacity on the demand side is well illustrated during the Green Revolution, which was the last major technological change in developing countries' agriculture aimed at counteracting famine and food insufficiency. In terms of production constraints in the input markets, the main problem encountered was one of distribution of farming inputs in the most efficient and equitable manner. Despite the lapses in governments' support schemes and programmes, the Green Revolution innovations led to significantly increased food supplies due to the cultivation of new High Yielding Varieties of crops such as rice and wheat. Yields could be as high as five times the traditional varieties. The success could be attributable in part to governments' commitment and the overall global support for the Green Revolution. The situation for biotechnology is not the same. An obvious difference is the way controversy has dogged biotechnology since its modern advancement in the 1970s. Opponents of biotechnology make a distinction between the technological approaches to the improvement of crops between the biotechnology paradigm and that of the Green Revolution. The innovation that were made in the Green Revolution were achieved using conventional techniques such as cross-pollination which is not much of a departure from the natural processes. In biotechnology, specifically genetic engineering, genes could even cross the natural barriers between organisms such as from animals to plants. The controversies add to the complications that need to be addressed in formulating public policies to replicate the Green Revolution success story with application of biotechnology.

Indeed, the countries that have made strides in biotechnology have the policy conditions well addressed if not explicitly stated, implicitly done through a national programme. For example, the governments of Japan, the Federal Republic of Germany and the United Kingdom fund a significant amount of generic applied science in biotechnology. In the U.S. there is strong support for basic research and relatively little for applied generic research and applied research (Cooper, 1994). Other countries outside the industrialised domain also provide concrete examples. Brazil's efforts to set up a public policy for biotechnology was consolidated in 1986 with the creation of the Special Biotechnology Secretariat (SBIO) attached to the Ministry of Science and Technology (MCT). Attempts to define a policy for this area evolved from earlier programmes starting with the National Alcohol Programme (PNA) in 1975. The government's policy for biotechnology has been characterised by a series of attempts to direct funds towards selected biotechnology-related targets (Galhardi, 1994, p.403). As Galhardi (1994) concluded, the success of policy initiatives for the industrial development of biotechnology in Brazil does not depend on an explicit policy for the area. It also depends, maybe principally, on implicit policies such as industrial and trade policies, and their mechanisms of implementation. Chapter 7, which examines the experiences of various countries to establish the best practice, will elaborate more on the issues.

James and Romijn (1997) also conclude that there is a range of policies that can ameliorate the process of technological capability building. In sub-Saharan Africa, for example, there is much more that can be done to favour local producers of engineering goods in the design of foreign aid projects and state procurement procedures. There is also considerable scope for institutions designed specifically to promote the acquisition of domestic technological capabilities, such as industrial extension services, technological advisory units and international information networks.

Indeed the policy range to enhance capacity must necessarily encompass the supply side. Rosenberg (1976) states that, "whether an active and creative scientific establishment in a country will make an important contribution to that country's economic growth depends upon a whole network of institutions and motivations outside of the scientific community. Translating new scientific knowledge into more productive techniques and into final product raises questions of inventive abilities and commercial talent." Policies put in place must effectively spawn and incubate innovative abilities and incentise commercial ventures.

It implies that governments must be prepared for the costs that must necessarily be incurred to engender the benefits. Wagner (1998) concludes in her assessment of biotechnology in Mexico that there is the need to recognise that, even as biotechnology's promises remain alluring, such technological innovation, also imply tremendous and expensive risk. The bottom line of biotechnology application is ultimately the same in all countries, regardless of their levels of development and their endowment of scientific and industrial resources - to stay at the cutting edge of the technology even with regard to cost. Clearly, this is the biggest obstacle to biotechnology development in the developing country context. But, the way round the obstacle is to begin in the first place and proceed from there along a determined trajectory on the basis of competencies and comparative advantage.

More importantly, the national planning and policy that must guide biotechnology development along the determined path cannot be treated in isolation from other policies. As Mytelka (2000) puts it, such policies "affect the presence of critical actors, their habits and practices, their knowledge base and the nature and intensity of their interactions." Thus this thesis argues primarily from what Mytelka (2000) terms an innovation system approach given the fact that one of the strengths of the approach is "its usefulness in identifying the interrelationship between policies" (Mytelka, 2000).

2.6 Planning Technology Development - Science and Technology Policy

To start with, this Technology Atlas Project (TAP) conjectured that a distinctive feature of human activity is making and using many kinds of physical and conceptual tools for the amplification of muscular and mental capabilities. The consequences of this is the departure from what was prehistorically a biological evolution of man to an intellectual evolution extending to the human societies - the aggregations of human beings - such that, "the shift is gradually from a natural world to a technological world" (ESCAP, 1989, p.23). On the surface it may appear to be a rather prosaic observation. However, it is a major step in conceptualising technology in the context of socio-economic development. The world today is highly technological and any nation with any kind of development aspirations must have the capacity to operate technologically. It becomes imperative then that nations must spell out with the utmost deliberation, adopt and carry through the relevant policies, strategies and programmes that will ensure that the necessary capacity is generated for the relevant technological activities.

The Science and Technology (S&T) Policy of a country consists of the principles and methods, "together with the legislative and executive provisions required to stimulate, mobilise, and organise the country's scientific and technological potential, so as to implement the national development plan and or strategy" (Goka, 1989, p.14). This definition is not substantially different from that of a technology policy, which is "a set of principles with which a country regulates its acquisition, utilisation, and disposal of technology for the purpose of achieving its development objectives" (Vitta, 1990, p.1471).

Given the centrality of S&T in the development plan of the country, the capacity to produce technology is infinitely more important than technology itself. "The prosperity of a nation depends not on the quantum of technologies it has amassed but on its capability to generate technologies" ((ESCAP, 1989, p.23). The principal aim of technology and science policy is thus to ensure the creation of effective technology support systems which bridge the gap between various industries and economic enterprises and the science base (Meltcalfe, 1997, p.724).

Many developing countries are faced with serious problems of technological underdevelopment and possess limited capabilities for assimilating and using existing productive knowledge to meet their social and economic needs. Consequently, their development strategies are seriously impaired and their participation in the global economy is hindered. The starting block for addressing their technological under-development and ensuring integration into the world economy is planning and implementing policies and strategies for technology development (Hassan, 2000). Over the years there have been S&T planning and there have been the enactment and implementation of S&T policies. S&T policies come in two broad types. There is the explicit policy, which states its objectives expressly, declares the methods chosen for pursuing them and ensures that public behaviour conforms to them. There is also the implicit S&T policy. In the absence of such an explicit policy, "public behaviour is not necessary random" and there exist implicit policies that "foreclose certain choices" in much the same way as an explicit policy may have done (Vitta, 1990, pp.1471-1472). Indeed, S&T planning and policy management in Sub-Saharan Africa has largely been of the implicit type using formal arrangements normally referred to as the UNESCO model in recognition of UNESCO's pioneering attempts to institutionalise science and technology policy in developing countries. The model consists of five basic elements:

a) Planning - scientific technological goals are set and policies and action programmes are developed to enable achievement;

b) Coordination - activities in the technological fields are monitored and aligned with existing policies.

c) Implementation - specific action programmes are carried out in selected technological areas;

d) Advice - information is given to the government and the public on scientific and technological issues;

e) Advocacy - support and resources are mobilised for the advancement of science and technology (Vitta, 1990).

Ghana very much adopted the UNESCO model and set up institutions for scientific and technological learning, research and development. The Council for Scientific and Industrial Research (C.S.I.R.) was established in 1958 to be an oversight institution for R&D in the country (Ghana Government, 1968 and 1976). The Kwame Nkrumah University of Science and Technology (KNUST) was also established in 1961 for scientific and technological manpower development (Ghana Government, 1961). Assessing the implementation of the UNESCO model, there appears to be only a limited success, at least in terms of these countries' abilities to improve on their development status. In fact, the economic indicators in most Sub-Saharan countries have worsened in the past decades. For example, in terms of human development the twenty-eight countries at the bottom of the ranking of 162 countries in the year 2000 were African countries, with life expectancy ranging from only 38.3 years to 55.6 years (UNDP, 2001, pp.133-148). The reason for the failure of the UNESCO model is not only the scarcity of resources, but also the inappropriate structures of the institutions that manage the policies and action programmes. What needs to be emphasised however is the deficiency in the approach to S&T policy formulation and implementation, which treat S&T as elemental and sectoral rather than holistic and cross-sectorial. The limited success of the UNESCO model underscores the under-girding premise of this thesis that *the whole is larger than the sum of its parts* and that biotechnology development must be holistic.

Indeed, the propelling force for S&T application has changed and so has the paradigm. There has been a move from inward-looking and import-substitution strategies to outward-looking and export-led strategies in economic planning. More importantly, the philosophy of liberalisation of markets and the drive for competitiveness as against the conservative efforts to exploit comparative advantages, has implied more focused and strategic ways of applying S&T policies than as done previously. What is more, the new technological developments such as in biotechnology have penetrated many sectors and have created the need for more strategic application of S&T in socio-economic activities (Freeman and Soete, 1997).

Ghana now has an explicit S&T policy, which though not passed through Parliament has been adopted by the Cabinet as a national document (Ghana Government, 2000). Until then, it pursued various implicit S&T policies whose agenda could be deduced from various sectoral action programmes and policies e.g. the national development plans (1960, 1972, 1995), agricultural policies (Operation Feed Yourself 1972, NARP 1989, AGSSIP 2000,) and economic policies (ERP 1983, SAP 1986). What most of these sectoral approaches have accomplished was to make the S&T in these policies and programmes residual rather than central. Against the background of the failures of the UNESCO model, the issue is whether with an explicit policy in place now, Ghana can move in the direction of achieving the technological objectives that are the pillars of middle-income country status. There are reasons to be doubtful whether this will happen primarily because the elemental or sectoral approach to technology utilisation and development prevails. For generic technologies such as biotechnology, the holistic approach is the key for success. The issue is not whether the S&T policy is implicit or explicit. For biotechnology development, success demands that the formulation and implementation of the relevant policies and programmes must be holistic.

2.7 Summary of Literature Review

The review of the literature has clarified certain key concepts that are guiding the study. Firstly, the concept of the multidimensional nature of technology is very essential for the study. It forms the basis for the methodological approach for assembling data and analysing them. Secondly, technological capacity is the totality of human resources of the requisite skills, the stocks of knowledge available, physical facilities and tools needed and the institutional framework for production. Building technological capacity therefore must go beyond mere acquisition of tangible instruments and facilities. Apart from this, there are critical imperatives pertaining to development of skills and conditioning of an ambient framework for achieving technological goals. Thirdly, biotechnology offers its own particular opportunities for innovations and technology development. It is a set of generic tools that has multi-disciplinary functions and cross-sectoral applications. As the tensions between supply and demand come into play, appropriate "tinkering" of the environment with the relevant policy instruments can facilitate capacity building significantly. However, this has to be done strategically with the effective formulation and implementation of the relevant policies. Fourthly, biotechnological capacity must evolve in context. The concept of the NIS underscores the important role of critical actors and their interactions in setting biotechnology development within the national context. Specific situations and needs will provide the relevant stimulus to the capacity building process. The application, development and management of biotechnology therefore become meaningful if driven by systemic conditions. These points are amplified in the conceptual framework developed for the analysis in chapter 3.

CHAPTER 3

THE METHODOLOGY OF THE STUDY

3.1 Introduction

Chapter 3 presents the methodology for the research. It contains among other things, details about the choice of samples, the sources and techniques for data collection and analysis.

In a research of this nature, Adeboye and Clark (1997) advocated for an approach that "starts from the side of problem definition". In this connection, prior to data collection for this study, there had been interviews and personal discussions with stakeholders over a period of time particularly through different projects conducted in 1997 and 1999. These interactions with the stakeholders in the course of the implementation of the projects, facilitated the definition of the issues in biotechnology capacity development from several perspectives.

3.2 The Conceptual Framework for Analysis

At the fulcrum of the thesis is the premise that *technological capacity as a whole is greater than the sum of its parts*. The composite technological capacity embraces components from both the supply and demand sides of technological innovations. The interplay of policy variables defines the environment for the building of technological capacity. To this extent, policy initiatives can serve as facilitators of the capacity building process acting on both sides of supply and demand of innovations.

There are two main sides to technological capacity namely the supply side and the demand side. In the delimited area of crop production, the supply side of innovation is fairly synonymous with the National Agricultural Research System (NARS). The supply function may be specified as:

S = f (**D**; internal factors, external factors) - (1)

Where **D**, an endogenous variable, = demand for biotechnological products.

Internal factors include government policies e.g. national development programme, trade and investment policy, Science and Technology culture, local market situation, R&D institutions, human capital, scientific infrastructure, information systems, national economic policy, educational policy, S&T policy, intellectual property regime, etc.

International factors include the global market, international state of the art of biotechnology, international collaboration, bilateral and multi-lateral assistance, international regulatory regimes of e.g. IMF, World Bank, WTO and Biosafety Protocol.

The internal and international factors determine the supply of biotechnology products both independently and in combination (the synergy effect) to enhance the production of biotechnology outputs. The demand for biotechnology products may be specified as:

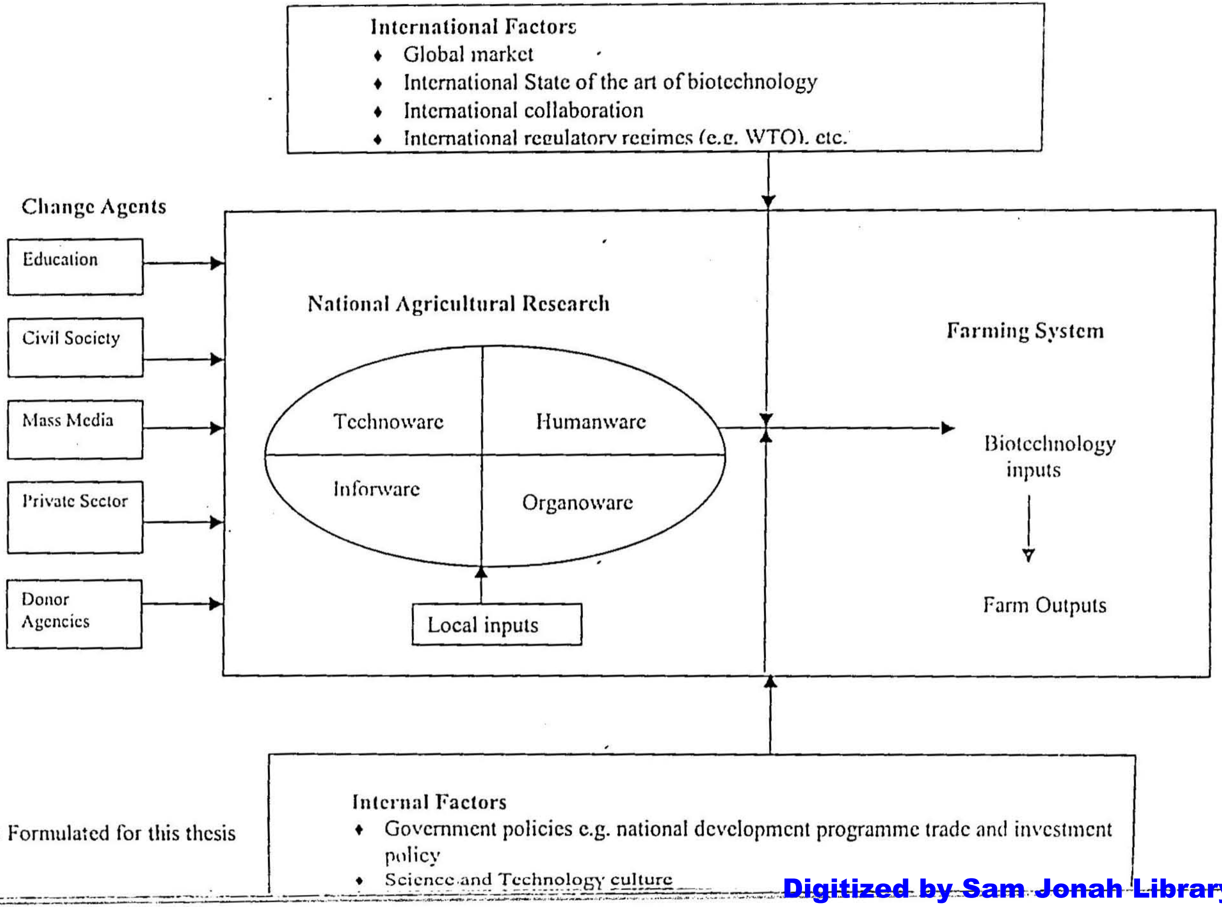
D = f (number of farmers, size of farms, frequency and intensity of use of scientific inputs, strength of linkages between extension officers and farmers, NGO activities in technology diffusion, government economic policies, etc.) - (2)

The equality of supply and demand determines the biotechnology capacity of the nation at any given time. Thus:

S = **D** = f (internal and external variables) - (3)

Changes in these exogenous variables impact positively or negatively on the nation's biotechnological capacity. For example, a well-focused research on some aspects of biotechnology and external funding is likely to add significantly to the stock of biotechnology knowledge. On the other hand, shortage of relevant scientific personnel and lack of funding is likely to result in stagnation in capacity building. The effects of some of these factors are discussed more fully in Chapter 8. (The diagram in Figure 3.1 summarises the framework).

FIGURE 3.1 BIOTECHNOLOGY CAPACITY BUILDING – THE CONCEPTUAL FRAMEWORK



Source: Formulated for this thesis

3.3 Methods of Data Collection

Data were collected from both sides of supply and demand of innovations as stipulated below:

(a) Supply Side

Generally, data were collected through:

- desk research,
- a survey of the scientific biotechnology institutions using structured questionnaire,
- interviews with the scientists and researchers, and
- inventory of physical facilities.

Questionnaires and interview guides were used for the collection of data focusing on among other things, the numbers and types of human resources involved in biotechnology, the techniques and facilities in use in the knowledge centres of the universities and R&D institutions, the nature of R&D activities, the constraints and the types of collaborations involved.

Data was also collected from policy institutions such as the ministries of S&T, education and agriculture. The data related to the current policy environment for the promotion of biotechnology development, biosafety and human resource development.

(b) Demand Side

Data on the demand side of the biotechnology capacity involved quantitative research in a case study. The research aimed at determining the potential demand for biotechnology products using the case of farmers. Questionnaires were administered to gather data on among other things the types of crops grown, farmers' profile, constraints, ability to adopt innovations, awareness of biotechnology and views on agricultural policies.

Key informants were also interviewed to address various aspects of the study. For example the assistance of technical experts were sought in assessing physical facilities in the biotechnology laboratories. There were discussions with senior government officials with regard to the issues and the constraints in policy formulation for biotechnology development in Ghana.

The survey of the scientific institutions was carried out in Accra, Kumasi, Akim Tafo and Tamale where the institutions were located. For example, in Accra the R&D institutions covered were BNARI (Kwabenya), and the University of Ghana (Botany, Biochemistry and Crops Science Departments). In Kumasi, the Crops Research Institute and KNUST were covered in the study. In Tamale, the University of Development Studies and SARI were covered. At Akim Tafo, data were collected from the Cocoa Research Institute. (See Appendix 5 for a list of interviewees)

To select the location for the case study on the potential demand by farmers, the key criterion was the capacity for production of local staples on the basis of data obtained from MOFA. The staples considered were maize, rice, cassava, yam, cocoyam and plantain because they were grown in all the regions in Ghana and data were available. (See Appendix 4) The rankings were determined for the production of these crops and the first region was selected for a survey of the farmers. The Eastern Region was the first on the basis of the production of these crops by ranking. (See Table 3.1 below)

Table 3.1 Ranking for the Production of Six Major Crops - 1999

Region	Maize	Rice	Cassava	Yam	Coco-yam	Plantain	Total Rank
Western	7	5	6	7	3	3	5
Central	5	10	5	8	5	5	6
Eastern	1	4	1	2	2	1	1
Greater Accra	9	7	8	9	7	7	9
Volta	6	3	3	4	6	6	3
Ashanti	2	6	4	6	1	2	2
Brong-Ahafo	3	9	2	1	4	4	4
Northern	4	2	7	3	7	7	3
Upper West	8	8	9	5	7	7	8
Upper East	10	1	9	9	7	7	7

Source: Based on data compiled by SRID, MOFA, 2000

After determining the region, the New Juaben District was randomly selected among a total of 15 districts. The New Juaben District was also considered suitable for the study given the fact that it has settler farmers coming from a diverse ethnic background such as Ewe, Ga-Adangbes and Kokombas, offering a fair reflection of Ghana's agricultural practices. At the heart of the New Juaben District is the Eastern Regional capital Koforidua. The district is therefore easily accessible though a few villages and hamlets were difficult to reach. The urban and rural interaction also provided a realistic social setting for the study given that, the study would undercover the impact of urbanisation currently coming into play in Ghana's agriculture.

3.4 Limitations of Study

Ideally, the sample should have been drawn from each of the 15 districts in the region to enhance the validity of the findings. Better still, the study should have been national covering all the regions of the country. However, limitation on resources did not make that possible.

3.5 Study Population

On the supply side of technological capacity, the sample population comprised the researchers and scientists in the universities and the research institutes. On the demand side the case study to assess potential demand involved farmers. The key informants included scientists, policy makers and agricultural extension officers. Interviews were also conducted in regulatory institutions such as the Plant Protection and Regulatory Services on the issue of biosafety.

3.6 Sampling

There was purposive sampling of the scientists i.e. the respondents involved in modern biotechnology for crop production. The purposive sampling was made possible by the pre-study activities mentioned above.

The sampling of farmers was randomly done with the assistance of two District Agricultural Extension Officers (DAEOs) of the New Juaben District. There were fifteen operational areas centred on key villages in the districts and Agricultural Extension Officers have been based in these areas. The two DAEOs in collaboration with the AEOs prepared a list of farmers they had been visiting over the years. The names of a total of 1,200 farmers were compiled. This became the sampling frame for selecting the sample. A total of 295 farmers were randomly selected and the structured questionnaires administered to them on the basis that given the uncertainty in making contacts, the range of acceptable sample population sizes (U) was calculated at the 90% confidence interval. This is given by: U = X ± Z SX, where X is the sample population, Z is the confidence interval and SX the standard error. (See Spiegel, 1972)

However, standard error (SX) = Standard deviation / square root of sample population (n) times the square root of (total population N minus sample population n, divided by N-1) where N is more than 30. Thus, given a total number of 1,200 in the sampling frame, assuming a standard deviation of 5%, which is equal to 60 (i.e. 5% of 1,200), the standard error SX is: SX = 60/ 17.2 times square root of ((1,200 – 2950)/ 1200 – 1)

= 60/ 17.2 x 0.868 = 3.055.

By substitution, the U = 295 ± 1.64 x 3.055 = 295 ± 5.

It implies that at the 90% confidence interval, the sample size must lie between 290 and 300.

3.7 Data Analysis

Responses from the survey on the supply side were collated and tabulated presenting frequencies and other statistics as appropriate. Data from the quantitative survey were analysed using the SPSS software. The questionnaires were coded and inputs were made into the computer. Statistics and other units of analysis were generated for discussion. Where necessary the relevant correlation tests were done between selected variables.

On the supply side, an attempt was made to determine the gaps in the country's technological capacity for the biotechnology innovations. This was done using as a basis, the common elements of best practice as derived from the experiences of other developing countries. Further analysis of the biotechnological capacity building in Ghana presents the policy options for capacity building.

CHAPTER 4

ASSESSMENT OF BIOTECHNOLOGICAL CAPACITY IN GHANA

4.1 Introduction

This chapter addresses the objective of finding out the biotechnology capacity in Ghana. It presents and discusses the results of the survey of biotechnology institutions, the human resources, the physical facilities, and information systems in the country under the sections *Organoware, Humaware, Technoware*, and *Inforware* respectively. The statement on the biotechnological capacity is mainly concerned with technology development and generation. Thus, the results presented here relate to the supply side of innovations and technology development. It is necessary to point out that there are issues that overlap across the four key sections. The issues are discussed under one or the other as appropriate.

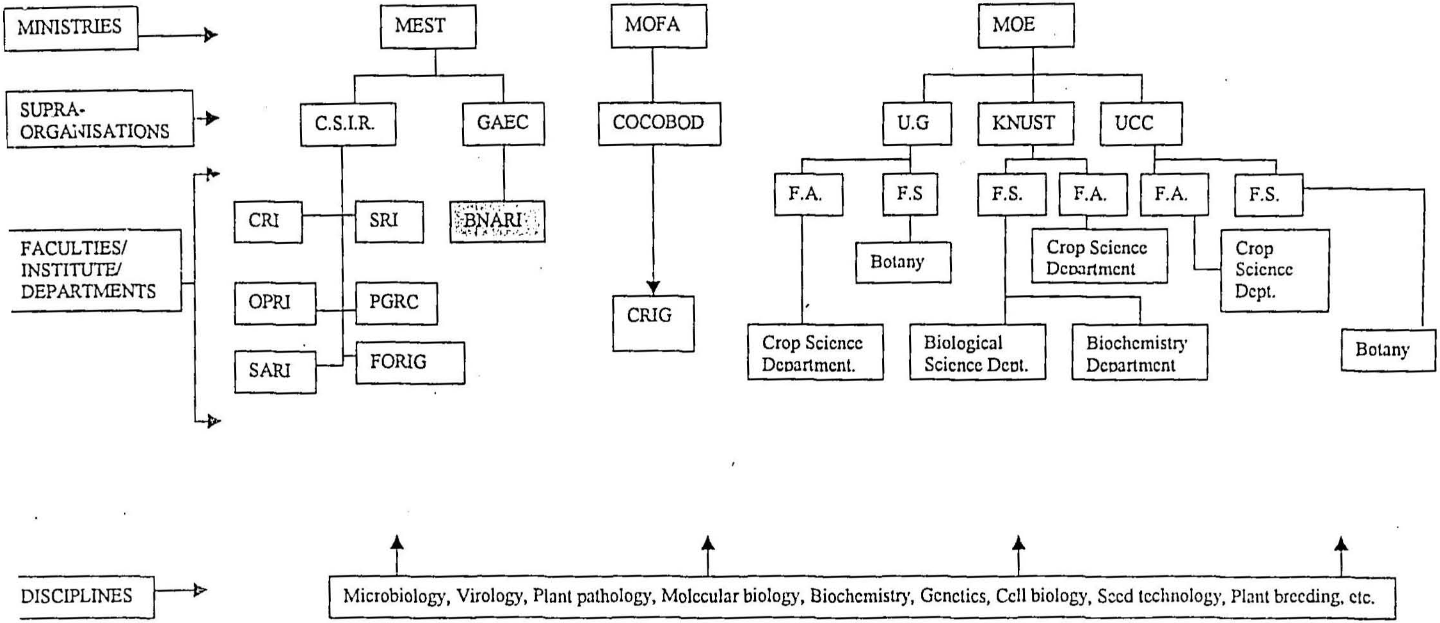
4.2 Organoware

This section mainly presents data and discussions on the organisational framework with regards to the locations of the biotechnology institutions in the respective sectors of the economy, the legislative framework, the local and external linkages and the policy environment. The aim is to assess the state of the organisational framework and identify the institutional, legislative and policy gaps.

4.2.1 Institutional Framework for Biotechnology R&D

The organisational framework on the supply side of innovation consists of institutions under three key ministries namely the Ministry of Environment, Science and Technology, the Ministry of Agriculture and the Ministry of Education. The biotechnology institutions are located in supra-organisations namely the universities, the C.S.I.R. and COCOBOD. (See the organisational chart in Figure 4.1 and also list of contacts with addresses in the appendix). In Ghana there are three fully-fledged or mature universities and two university colleges. The faculties of science and agriculture in the mature universities have biotechnological capabilities. This is to be expected since biotechnology development falls within the purview of their respective mandates for human resource development. The extent to which they are able to address this mandate effectively will however be shown in the subsequent sections. In the C.S.I.R., biotechnology is also important in the research activities going on in the key agricultural institutions including the Crops Research Institute (CRI), the Savanna Agriculture Research Institute (SARI) and the Oil Palm Research Institute (OPRI). COCOBOD, which is under MOFA has oversight responsibilities for the Cocoa Research Institute of Ghana (CRIG).

Figure 4.1: Organisational Framework for Biotechnology Research and Development



Source: Derived from the analysis of the thesis data

NOTE: Abbreviations and acronyms used are as defined in thesis. See the list of abbreviation. The following are not

The core institution for biotechnology development is BNARI and it is under the auspices of the Ghana Atomic Energy Commission. The institute was set up to explore the application of isotope, ionising radiation and other nuclear and biotechnology techniques for increased agricultural and economic development. It aimed at among other things, to:

- develop better varieties of economic crop plants,
- provide optimal conditions for crop cultivation,
- increase and stabilise agricultural production,
- raise the level of nutrition by improving food quality,
- protect crops and livestock against losses through insect attacks and diseases,
- preserve food for animal and human consumption,
- facilitate international trade in agriculture produce (BNARI, 1995, pp.6-7).

The establishment of a sole institution for biotechnology suggests that Ghana realises the importance of biotechnology in national development. The placement under GAEC is understandable given the historical origin. However the apparent linkage of biotechnology and nuclear science appears rather contrived. It is however important that BNARI develops to its full potential to address the stated functions.

4.2.2 The Regulatory Framework for Biotechnology

The regulatory and monitoring framework for biotechnology applications, development and management is an important component of the organisational framework on account of the biosafety concerns. In Ghana, this is poorly developed and no specific institution has been fully established to address this. However, there are various institutions whose functions partially address certain biosafety concerns. Table 4.1 below summarises the framework.

Table 4.1 Institutions of Biosafety Concern

Name	Year Established	Current Legislative Date	Related Biosafety Mandate
Food and Drugs Board	1992	Food and Drugs Law, 1998	To control the manufacture, importation, exportation, distribution, use and advertisement of food, drugs, chemical substances and medical devices.
Ghana Standards Board	1967	NRCD 173, 1973	To seek the promotion of standards in public and industrial welfare, health and safety.
Plant Protection and Regulatory Services Department (PPRSD)	1965	The Plant Quarantine Act, 1996	Regulation of imports and exports of plant materials
Ministry of Environment, Science and Technology	1994	Government Directive	Oversight of the Environment, Science and Technology Sector
Ministry of Food and Agriculture	-	Government Directive	Oversight of the agricultural sector
Environmental Protection Agency (EPA)	1974	EPA Act, 1994	To conduct and promote investigations, studies, surveys, etc., relating to the improvement and the maintenance of sound ecological system
Council for Scientific and Industrial Research	1958	CSIR Act, 1996	To advise on S&T advances relevant to development; carry out scientific research management, conservation of natural resources, etc.

Source: Revised from Essegbey and Stokes (1998)

These institutions individually address concerns in the areas of regulation, monitoring, policy formulation and implementation. The PPRSD holds responsibility for regulating and monitoring the importation and export of plants. The Plant Quarantine Act of 1996 fully empowers them to quarantine foreign plants entering the country and screen them to ensure ecological compatibility with Ghana's ecosystem. This mandate apparently gives them a role in biosafety as for example when genetically modified plants are being imported into the country. However, their screening is based on phenotypic inspection and the analysis for phyto-sanitary safety. The PPRSD does not have the facilities to determine genetic modification and identify the specific types of modifications that have been done and their effects (Personal Communication, 2000). In that sense, they are handicapped in performing the necessary risk assessment functions required under a biosafety regime.

In connection with evaluation of genetically modified plants, another partially relevant system is the Varietal Release Committee set up under the auspices of MOFA. It is made up of experts from some of the scientific institutions and ministerial divisions. Applications for the release of improved varieties are made to the committee with submissions of the plant varieties for field-testing. The committee gives approval for the release before the varieties are passed on to farmers. This committee was set up mainly to evaluate improved hybrids developed in the local institutions such as Crops Research Institute and the agricultural research stations of the universities. They also suffer from the same legislative and technical handicaps associated with the PPRSD.

The other remaining institutions listed in Table 4.1 are rather more removed from the biosafety functions. For example the EPA has the mandate to conduct and promote investigations, studies and surveys relating to the improvement and maintenance of sound ecological systems. The EPA does not define biosafety as being at the core of its mandate. It is already too engrossed with problems with environmental pollution arising from mining and other industrial activities and apparently these are the areas the agency seems best equipped to address. It does not have the capacity to assess biotechnology products.

The GSB and the FDB are the institutions, which have the mandate to assess food products and ensure their safety for consumers. Biosafety also relates to the safety of the products whether imported or produced locally. Both institutions do not have the capacity to undertake the complex testing procedures to identify any dangers in consuming food products from genetically modified ingredients. The C.S.I.R.'s role is basically advisory. It is to advise on S&T advances relevant to national development and carry out scientific research management, utilisation and conservation of natural resources. It appears therefore that there is a major lacuna in the regulatory arrangement for biosafety in Ghana. Though there are some initiatives to address this, things have not been finalised yet.

For example, a National Biosafety Council was inaugurated in April 2000 to address the specific concern of biosafety. The 13-member committee draws on experts from the Universities, research institutes, ministries, industry, legal profession and farmers. The Council's terms of reference include:

- formulation of policies, regulations and procedures for biosafety in the country,
- co-ordination and monitoring of biotechnology activities in the country,
- development of human and institutional capacity in biosafety,
- co-ordination of Ghana's participation in global and regional discussions on biosafety,
- collaboration on sub-regional and regional initiatives (Personal Communication, 2000).

A Biosafety Clearing House has also been established at the Ministry of Environment, Science and Technology (MEST) to facilitate exchange of scientific, technical, environmental and legal information. Apparently, the biosafety regime in Ghana is very young and it will take some time for it to develop.

Some international conventions also have the potential to facilitate the development of biotechnology in Ghana. For example the Convention on Biological Diversity (CBD) to which Ghana is a signatory, enjoins contracting parties to put in place policies for the handling of biotechnology and distribution of its benefits. Specifically (UNEP, 1992):

- Article 19, paragraph 3 enjoins parties to "consider the need for and modalities of a protocol setting out appropriate procedures, including, in particular, advance informed agreement, in the field of the safe transfer, handling and use of any living modified organism resulting from biotechnology that may have adverse effect on the conservation and sustainable use of biological diversity".

- Article 8 (g) enjoins contracting states to "establish or maintain means to regulate, manage or control the risks associated with the use and release of living modified organisms resulting from biotechnology which are likely to have adverse environmental impacts that could affect the conservation and sustainable use of biological diversity, taking into account the risks to human health."
- Article 10 (b) calls on parties to "adopt measures relating to the use of biological resources to avoid or minimise adverse impacts on biological diversity."

In 2000, the Biosafety Protocol was concluded in Montreal. It remains to be seen how committed the advanced countries will be to the Protocol given the controversies that surrounded its negotiation and given the fact that the U.S. is still not a party to the CBD under which the Protocol was contracted. It remains also to be seen how Ghana can take advantage of the CBD and enhance its biotechnology capacity. But the lack of a fully established institution for biosafety leaves a big gap in the organisational framework for biotechnology development.

Another area, which needs further action, is the area of Intellectual Property. A major development associated with biotechnology is the dominance of proprietary rights in innovations. It is a major factor in the application and transfer of biotechnology. Currently, the Registrar-General's Office is responsible for the registration and administration of industrial property rights. Ghana's industrial property regime provides avenue for appropriating ownership of inventions. The Ghana Patent Law of 1994 with its legislative instruments (1996) gives substantial coverage of intellectual property to inventors but not living organisms. There is also the alternative of patenting through the African Regional Intellectual Property Organisation based in Harare. However, the problem with the intellectual property system has to do with weakness of the legislation regarding planting materials. The Registrar-General's Office has proposed to institute a plant breeder's right protection similar to those under the Convention for the Protection of Plant Varieties (UPOV). The Protection of Plant Varieties Bill of 2000 aims at providing "incentive for plant breeding hence facilitating improvements in the quantity, quality, cost of food, fuel, fibre and raw material for industry" (Ghana Government, 2000b). It is provided for that the approval of the plant variety will be given on the basis that it is new, distinct, uniform and stable. These are the criteria, which define a plant variety under the UPOV. Therefore even if the bill does not explicitly state Ghana's intention to accede to UPOV, it is adopting the UPOV approach to protection of plant varieties.

This however only begs the issues which centre on the usefulness of the system in providing improved planting materials to the large majority of farmers who already are financially emasculated even without the added cost of protected planting materials. There are the other issues of scientists' lack of awareness of the intellectual property regimes and the ineffective linkage between protectors of the rights and the users. More importantly, it is hard to see how indigenous knowledge can be protected under the plant breeder's rights. What is usually appropriate for protection of traditional knowledge systems is a *sui generis* system that spells out the rights of indigenous people and how these rights can be accessed (Seiler, 1998). These are some of the constraints that make the country's regulatory system rather inhibitory for biotechnology development.

Internationally, the Trade-Related Aspects of Intellectual Property Rights (TRIPS) instituted in 1994 will also have an impact on Ghana's intellectual regime. TRIPS provide the advantage of a harmonised intellectual property regime. However, there are disadvantages coming, as it does with the imposition of an intellectual property system that is not entirely institutionalised in the Third World context. Members of the World Trade Organisation such as Ghana have to institute monitoring and proactive systems to enforce intellectual property. More importantly, one can anticipate a truncation of the country's innovative capabilities based in the informal sector, which largely operate through copying and imitation.

4.2.3 The Roles of Foreign Collaborating Agencies in Biotechnology R&D

The organisational framework for biotechnology development is defined within the national context. But there are linkages within and outside the confines of the framework. The survey explored the nature and extent of the linkages. (See Table 4.2 below)

Table 4.2 Foreign Collaborating Agencies and their Roles in Biotechnology R&D

Agency	Funding	Joint Research	Training	Technical Assistance
Eastern Washington University, U.S.	+			+
DANIDA, Denmark	+			
International Atomic Energy Agency, Italy	+		+	+
International Institute for Tropical Agriculture, Nigeria			+	+
INIFAP, Mexico				+
British Chocolate and Confecting Companies Alliance	+			
Natural Resources Institute	+			+
CABI (U.K. and Kenya)				
Cocoa Research Institute of Nigeria		+		
Cocoa Research Inst. of Ivory Coast		+		
WECAMAN	+			
University of Wiscousin, U.S.	+	+		
University of Aberdeen		+	+	+
North Arizona University		+	+	+
Agronomic Society of America	+			
John Innes Center, U.K.		+		+
University of Florence, Italy		+	+	+
Common Fund for Commodities (CFC)	+			

Source: Field Survey, 2000

There are four main roles for foreign agencies in biotechnology R&D in Ghana. They provide funding, training, technical assistance (in terms of equipment and reagents) and some agencies jointly implement the projects with the local institutions. Table 4.2 presents the roles of the foreign collaborating institutions in the projects surveyed. The main roles were that of funding and the provision of technical assistance. The foreign collaborating institutions provided the critical resources for biotechnology R&D to be carried out. Institutions such as the Danish Development Agency (DANIDA), the

International Atomic Energy Agency (IAEA) and the Natural Resource Institute played major roles in biotechnology capacity building in Ghana. The IAEA had been instrumental in the setting up of the Biotechnology and Nuclear Agricultural Research Institute (BNARI) in Ghana. IAEA has had a long-standing collaboration with the Ghana Atomic Energy Commission (GAEC) and through that GAEC was able to establish BNARI as an institute for biotechnology research in 1993 (BNARI, 1995, p.3).

Over the years, the IAEA has provided funding for research, training of expertise and supplied needed biotechnology equipment such as autoclaves and laminar flows as well as chemicals. The IAEA has also provided some of such assistance to the Cocoa Research Institute. It funded research activities including mutation breeding for resistant varieties against the cocoa swollen shoot disease (Adu-Ampomah, *et al*, 1991).

The foreign universities also played an important role in biotechnology capacity building. Apart from providing technical assistance including the supply of expertise on exchange programmes, the foreign universities jointly implemented R&D projects with local institutions. This facilitated the transfer of knowledge and expertise. For example, Eastern Washington University in the U.S. was instrumental in setting up the Biotechnology Unit at the Botany Department of the University of Cape Coast. As it were, the only gene gun in the country at the time of the study was supplied by this university and made possible the enhancement of capacity for genetic engineering. The project involves the transformation of friable embryonic callus through bombardment with selected genes with the aim of producing virus-free cassava of an enhanced protein content (Personal

Communication, 2000). The project is still in progress and the continued exchange of materials and information on the Cassava Project has the potential for putting the local researchers at the forefront of plant biotechnology in Ghana. Table 4.2 also shows that private sector organisations such as the British Chocolate and Confecting Companies Alliance and the Common Fund for Commodities provided funding for biotechnology R&D. Predictably, their funding went into their areas of interests. These organisations funded cocoa research in order to benefit directly from the research. It did not negate the important role they were playing in biotechnology capacity building. Indeed the point needs to be made that as far as international trends go in the advanced countries, private sector's investment provided the pivot for biotechnology development (Avramovic, 1996, p.61). Both foreign and local private funding of R&D can be an important determinant in the biotechnology development process in Ghana. In the more progressive developing countries, there has been some local private sector participation in the biotechnology development process. In Mexico for example, though multi-national corporations such as Ciba-Geigy and DuPont had made investments to engender biotechnology development, local corporations such as Grupo Pulsas and Empresas La Moderna SA had also made important investments (Wagner, 1998, pp.61-73). Chapter 7 further discusses the issue of private participation in the analysis of experiences of developing countries in biotechnology development.

4.2.4 Local Collaboration in Biotechnology Research

The survey also found local collaboration among the various institutions in Ghana as shown in Table 4.3.

Table 4.3 Local Collaborating Institutions in Biotechnology Research

Nature of Project	Implementing Agency	Collaborating Agencies
Sustainance of Odum (Irroko) production in West Africa	Forest Research Institute	
Improvement of yam	Crops Research Institute	PGRC, SARI, FRI
Investigation of New Cassava Disease	Crops Research Institute	
Genetic enhancement of Pearl Millet against Downy Mildew	SARI	
Development of Genetic Diversity in Kola using molecular markers	Cocoa Research Institute	PGRC
Development of diagnostics for CSSVD	Cocoa Research Institute	
Integrated Pest Management and Development of botanical pesticides	Cocoa Research Institute	Cocoa Services Division, MOFA
Improvement of Cassava	Crops Research Institute	PGRC, SARI
Improvement of Coffee Cultivation	Cocoa Research Institute	Cocoa Services Division, OPRI
Cowpea Improvement	Crops Research Institute	SARI
Increase N-fixation in green legumes	SARI	
Crops improvement using molecular biology techniques	SARI	
Characterisation of local yam	SARI	Crops Research Institute
Biological control using mycopesticides on cocoa	Cocoa Research Institute	
Breeding resistant cassava against diseases	BNARI	KNUST
Developing resistant cocoa to Blackpod disease	Cocoa Research Institute	BNARI
Development of clonal museum of citrus	Crops Research Institute	U.C.C., U.G., Soil Research Institute, MOFA, PGRC
Provision of improved Musa sp. Germplasm for farmers	Crops Research Institute	BNARI
Development of citrus-based farming systems	Crops Research Institute	MOFA, U.G., KNUST, UCC, PGRC, SARI
Development of planting materials of miracle berry	Crops Research Institute	BNARI
Production of disease resistant mango plantlets	Crops Research Institute	
Production of cassava planting materials	Crops Science Department	Crop Research Institute
Characterisation and selection of beneficial strains of Rhizobia	KNUST	
Micro-propagation of banana, pineapples and other crops	BNARI	
Transformation of cassava for viral resistant and quality improvement	UCC Botany Dept.	

Source: Field Survey, 2000

Collaboration among the local institutions as shown in Table 4.3 was fairly high in biotechnology R&D particularly as related to areas of common interest. Out of the 24 projects recorded, 14 involved two or more research institutes – more than 58% of the total projects. Local collaboration ensured more effective use of available expertise and a means of putting a national character on the project. For example in the project on yam improvement being implemented at the Crops Research Institute, there was collaboration with the Plant Genetic Resources Centre (PGRC) which was involved in germplasm conservation and had some accessions of the local yam species already in conservation. There was also collaboration with the Savanna Agricultural Research Institute located in the ecological area of most of the yam production in Ghana. Crops Research Institute provided expertise in crop breeding, agronomy and entomology whereas the PGRC had expertise in botany and conversation. SARI also provided expertise in agronomy particularly as pertaining to the crops of the savanna farmlands. This was vital for the research process itself as well as the future extension of the outputs to the farmers. The Food Research Institute, which had the mandate in developing food-processing technologies, was also involved in this project. Thus, table 4.3 illustrates the point that a feature of biotechnology R&D in Ghana is inter-institutional collaboration and this facilitates the use of resources wherever they are available. The question though is why if inter-institutional collaboration is good, it is not a feature in all the projects identified. The answer lies in the constraints of collaboration.

Indeed, collaboration among institutions as found out in the survey did have its own problems and could become constraints in themselves. For example, poor collaboration was one of the barriers cited in biotechnology projects. There were situations of difficulty in communication and exchange of information vital for the progress of the projects. With electronic communication one would have expected that such problems would be non-existent. However, the problems existed mainly because many of these institutions did not have adequate and up-to-date computer resources and Internet connections. Moreover, problems of transportation across long distances may hinder work on the project. SARI was in Tamale, about 200 km north of Kumasi where Crops Research Institute was located and about 400 km away from Accra where Food Research Institute was located. Transportation for meetings can sometimes be problematic mainly also because if the researcher did not have his own means of transport, travelling by the public transport could be an undesirable chore from their stations. The point can be made though that on the balance, the advantages of inter-institutional collaboration outweighs the constraints and there is need to encourage this.

Collaboration can also be enhanced if there is a point of co-ordination of the various biotechnology initiatives not necessarily in terms administrative oversight but in terms of ensuring access to information on what is being done and where and by whom. Given the generic and cross-sectoral character of biotechnology, development initiatives are bound to proliferate independently and with diverse objectives. The organisational framework has shown that at least three key ministries are connected. However, co-ordination is vital for synergistic impact. The function of co-ordination through, for example, the effective dissemination of information on the on-going activities will also contribute to minimising duplication and maximise returns on resource allocation.

4.2.5 Funding of Biotechnology R&D Projects

Table 4.4 Funding of Biotechnology R&D Projects

Source of Funding	Number of Projects Funded by Sources			
	100%	75-99%	1-25%	Other %
Government	3	3	14	9
Donor	3	15	1	8
Private sector			3	
In-house			4	
Other sources				2

Source: Field Survey, 2000

Table 4.4 shows that, the highest levels of funding come from the donor agencies. Both government and the donor community sponsor some projects all by themselves (3 projects each). However, donors funded 15 projects with between 75-99% of total funds. The government complemented with funding ranging between 1-25%. The institutions also used funds generated in-house from commercialisation activities. Private sector also provided funds in some of the institutions. For example, Guiness Ghana Ltd., are supporting research into the use of local raw materials in its brewing industry (Personal Communication, 2000). It contracted the Crops Research Institute to develop, screen and select cassava varieties with the following characteristics:

- starch gelatinisation temperature range (GTR) of between 63 and 67 degrees or lower
- high yielding
- low cyanogenic potential
- resistant to major pests and diseases, and

- adaptable to areas of production.

In terms of biotechnology development, internally generated funds are the critical means of sustaining institutional activities. Indeed, the current drive towards commercialisation of R&D in the country imposes an imperative on the public research institutions to redouble their efforts to commercialise. The revision of the establishment legislation clearly specified the functions of the Council as, inter alia:

- to institute a system of contract research to ensure that research being carried out in the Council is relevant and cost effective;
- to encourage and promote the commercialisation of research results (Ghana Government, 1968, pp.2-3).

At present the funds being generated internally simply could not match the levels of expenditure of the institutes. It seems to suggest that the drive for commercialisation in the C.S.I.R since the late 1990s has not seen much gain. For example, for the year 2000 the Crops Research Institute, realised a total of 76.471 million cedis through commercialisation activities as against a total expenditure of 6.552 billion cedis (Crops Research Institute, 2001). Of the amount generated internally, only about 5.5 million cedis came from commission on foundation seeds and sale of breeder seeds, which might be described as the core institutional activities. R&D institutions need to strategise to enhance the generation of funds internally in order to ensure sustainability of their activities.

4.3 Humanware

The human resource is a critical component of the technological capacity. The expertise and the mechanisms for developing that expertise or more appropriately, the capability, lead to some of the issues regarding the increasing gap between the developing countries and the developed countries. The survey therefore explored some of the issues.

4.3.1. Biotechnology Human Resource for Crop Agriculture

For biotechnology application in crop agriculture, the human resource is as critical as - if not more critical than - the physical facilities needed. Biotechnology application is also knowledge-intensive and the human resource must be well trained with opportunities for up-dating knowledge. Table 4.5 shows that in terms of high-level expertise, Ghana has an appreciable number of researchers and educators.

Table 4.5 Expertise of Staff Involved in Agricultural Projects

Qualification	Number
Ph.D.	45
M.Phil./ M.Sc.	34
B.Sc.	8
Diploma	26
Total	113

Source: Field Survey, 2000

A total of 113 manpower of all levels of qualification were found engaged in one project or the other in the universities and research institutes (as listed in Table 4.5) with about 40% of these having been trained to Ph.D. level. Also, about 75% of the total manpower holds either a qualification of master's degree or Ph.D. The question of whether this human resource is adequate especially against the country's aspirations of middle-income status is yet to be answered. However, the data indicates that Ghana appears to have a seed crystal for precipitating a mass of high-level human resource for biotechnology.

A more detailed survey of the C.S.I.R. as the core institution for R&D was carried out. In C.S.I.R. biotechnology institutions, the following details emerges as shown in Table 4.6:

Table 4.6 Specialisation of Researchers in Selected C.S.I.R. Institutes 2000

Area Specialised	OPRI		S.R.I.		F.R.I.		C.R.I.		FORIG		Total
	M.	Ph.D	M.	Ph.D	M.	Ph.D	M.	Ph.D	M.	Ph.D	
Breeding	2	-	-	-	-	-	4	6	-	-	12
Entomology	3	1	-	-	-	-	1	4	-	-	9
Pathology/ Virology	3	-	-	-	-	-	-	4	-	-	7
Soil Science	-	-	8	4	-	-	-	-	-	1	13
Food Micro-biology	-	-	-	-	4	2	-	-	-	-	6
Food Proc. Tech.	-	-	-	-	6	4	-	-	-	-	10
Seed Tech	-	-	-	-	-	-	1	1	1		3
Plant Physio.	-	-	-	-	-	-	1	2		-	3
Other	-	-	-	-	-	-	-	-	-	1	1
Total	8	1	8	4	10	6	7	17	1	2	64

Source: Field Work, 2000; Forth-coming Annual Reports

The difficulty in discussing specialisation of the human resource relates to the overlaps that prevail in the attempt to define categories or disciplines. For example a researcher is a molecular biologist and a virologist (at CRI) as well. A researcher may also be a microbiologist and a plant nutro-physiologist (at SRI) as well. Thus Table 4.6 aims at is to depict the diversity of the specialisation and make the point that, the country has quite a significant level of specialisation for biotechnology activities. As shown in Table 4.6, in the selected key C.S.I.R. research institutions, 64 researchers trained up to a minimum of a master's degree are actively working. Indeed almost 50% hold a Ph.D. It goes to confirm the point that, there is a core of scientists in Ghana that have potential to enable the country realise the benefits of biotechnology. Nevertheless, there is need to put in place strategies for human resource development to ensure the quantitative and qualitative improvement of the human resource (Essegbey *et al*, 2000). As shown in Table 4.15, there are institutions where there are trained expertise but no lab facilities for them to work in. The motivation in terms of supplying the requisite physical resources for their work is lacking. Thus the skills, that the manpower has acquired is not utilised.

4.3.2 Stimuli for Initiating Biotechnology R&D Projects

Table 4.7 Stimuli for Initiating Projects

Stimulus	Number of Projects
International collaboration	2
Academic work (e.g. Ph.D, M.Phil.)	6
End-user demand	4
Farming problems	10
National programme	5
Researcher's own interest	1

Source: Field Survey, 2000

An important factor in the adoption of the use of the results or outcomes of the projects is the stimulus for the projects. Table 4.7 shows that many of the projects were stimulated by problems observed on the farms. Table 4.9 has shown that biotechnology research and development were directed at local agricultural priorities in terms of the kinds of crops researched on. Table 4.7 provides further illustration of the focus of biotechnology R&D on local problems. End-user demand and the stimulus of national programming also emphasise that focus.

Academic work however scores high - the second highest - as a stimulus for biotechnology R&D. If it were academic work purely for its own sake, then it would have been undesirable. But as it were, these academic works were centred on local problems that needed research solutions. In the case of crop agriculture, farmers wanted planting materials better able to withstand environmental stresses such as the case of cocoa and the Cocoa Swollen Shoot Virus Disease. But it is one thing having one's academic interests coinciding with local problems and it is another thing actually being committed to solving the problems on the ground. The academic interest may stimulate the research but there is no guarantee of commitment to solving the actual problem on the ground. This point is clarified later in the next chapter presenting the case study of farmers in the New Juaben District. The point also links to the issue of diffusion of R&D results, which is presented in the next sections.

International collaboration also provided a stimulus for projects. It was inevitable that this should be the case given the limitation of local resources. As was shown in Table 4.2, international collaboration came in various forms. If foreign collaboration was the only reason for initiating a project and the project was not in line with local priorities, then it was not desirable. But the same point applied to other stimuli such as academic pursuit and researcher's own interest. Some researchers indicated that in addition to the stimuli of prospects for international collaboration and academic pursuits, other stimuli such as farmers' demand for new varieties or improved quality materials came into play.

4.3.3 Research and Development Application Areas in Crop Agriculture

Table 4.8 shows R&D application areas as found in the institutions surveyed.

Table 4.8 R&D Application Areas

Type of Crop	No. of R&D Projects	Type of Crop	No. of R&D Projects
Cocoa	6	Banana	1
Maize	1	Coconut	1
Cassava	8	Millet	1
Coffee	1	Odum	1
Kola	1	Yam	1
Cowpea/	2	Citrus	1
legumes	1	Miracle Berry	1
Mango	1	Soil	1
Plantain/	1		
Total	22		8

Source: Field Survey, 2000

A total of 28 biotechnology R&D projects were being carried out in the various institutions. These projects generally involved crops grown by local farmers. Cassava had the highest number of projects with 8 projects followed by cocoa with 6. This is understandable given the fact that cassava is a major staple in Ghana and forms a component of almost every daily meal in most parts of the country. Cocoa is the leading cash crop and an important source of the country's foreign exchange. It is therefore to be expected that a lot of R&D efforts will be invested in it to the extent that an institute has been established for cocoa R&D.

On the whole the crops attracting attention in the R&D sector are local crops, which generally are of priority in Ghana. At the National Stakeholders' Conference held in December 1999 at Elmina, the stakeholders' undertook a priority-setting exercise for biotechnology application in the sectors of agriculture and health. A total of 10 crops were prioritised in the order of cassava, maize, cocoa/sheanut, cotton, yam, cowpea, horticultures, oil palm/ coconut, plantain/ banana and rice (Essegbey et al, 2000). Out of these 10 crops, seven were listed in Table 4.8 as already being worked on in the research laboratories. The results illustrate the point that R&D activities in the country as far as biotechnology is concerned are very relevant to the needs of the country. Furthermore, Table 4.9 shows the categories of problem areas biotechnology R&D are being focused.

Table 4.9 Nature of Problems Addressed

Description of Problem	Number of R&D Projects
Disease resistance and control	13
Crop quality improvement	2
Biodiversity conservation	5
Pest management	6
Early maturity	1
Increase in yields	3
Soil fertility	2
Total	32

Source: Field Survey, 2000

The problem of crop diseases, which is probably the most crucial hindrance to crop production for farmers, attracts the highest number of projects. Pests, which are another crucial problem for farmers also, attract a high number of R&D efforts. Biodiversity conservation and the problem of yields respectively attract the next highest number of R&D projects. It must be mentioned that some projects address more than one problem and it is reflected in the total number of biotechnology projects addressing the problems. But again the results buttress the point that R&D activities are directed at local problems and therefore could have potential for applicability.

4.3.4 Planning of R&D Project Implementation

Table 4.10 Planned Duration of R&D Projects

Starting year	<90s	90	91	92	93	94	95	96	97	98	99	00
No. of projects started	5	1	1		2		1	6	2	6	2	2
Ending year	98	99	00	01	02	03	04	05	06	07	08	Don't know
No. of projects ended	1	1	4	1		1	1		1			18

Source: Field Survey, 2000

The commencement and ending of projects is a reflection of the extent of planning and the seriousness with which plans are followed in the R&D efforts. Table 4.10 presents results giving some indications about the planning of the projects in terms of the commencement and completion of the projects. On the average, two projects were initiated every year between 1990 and 2000. One project was planned for completion between 1998 and 2006. Though no statement can be made about the variance between planned date of completion and actual date of completion, what stands out in Table 4.10

is the data that out of the 28 projects, the researchers working on 18 projects (about 64%) did not know when the projects would end. Naturally the initiators of the projects were specific in the duration of the projects in their project proposals. However the irregular provision of resources for execution as well as other constraints contributed to extending the duration of the projects, making it rather difficult to say when exactly some of the projects would end. In the case of some of the projects - such as in the area of biodiversity conservation - they were designed to continue for an unspecified number of years. The highlight of the data in Table 4.10 is simply that in the execution of biotechnology projects, the timeframe specified was not adhered to due to various constraints. In this regard, twenty-six of the 28 projects found in the survey were on-going projects. Five of these projects had been going on since 1991. The issue of completion of projects relates to the previous issues discussed regarding the planned duration of the projects. Fundamental constraints in the implementation of the projects have not made it possible for adherence to the stipulated time schedules.

4.2.5 Constraints in Biotechnology Research

A total of 12 main categories of constraints were identified. It was necessary to determine the relative importance of the constraints in order to formulate the appropriate mechanisms to address them. In this regard, the author made effort to rank the constraints in order of priority on the basis of the frequency cited by the respondents and the ranking of the constraints by the respondents. To this end, the final ranking of the constraint in biotechnology research was determined as:

$P = MF - LR\ (MCC - n) - r$. Where: P = priority ranking of the constraint

MF = maximum frequency = 12 x 4 = 48

LR = lowest rank order = 4

n = frequency of barrier

r = sum of the ranking from the responses

MCC = number of main categories of constraints = 12. The number *48* is the maximum frequency (MF) obtainable for any of the constraints i.e. 12 times *4*, with the *4* being the lowest ranked (LR) order of importance from the responses. The number of main categories of constraints (MCC) is 12. Also, *n* is the frequency cited of barrier and *r* is the sum of the ranking of the responses. Table 4.11 presents the rankings using this formula.

Table 4.11 Constraints in Biotechnology Research

Constraint	Frequency Cited (n)	Sum of ranking (r)	Priority Score (P)	Priority Rank
Inadequate funding	12	16	32	1st
Lack of equipment	10	15	25	2nd
Poor supply of reagents	9	19	17	3rd
Lack of transport	7	13	15	4th
Inadequate laboratory infrastructure (e.g. lab. Space, lack of air conditioner, unreliable power)	6	14	10	5th
Inadequate human resource (e.g. breeders, technicians, molecular biologists)	8	22	10	5th
Poor collaboration	5	12	4	6th
Pest infestation	2	8	0	7th
Intellectual Property Rights	2	8	0	7th
Poor supply of local materials				
Natural disaster	2	8	0	7th
Other (e.g. stealing specimens)	2	8	0	7th

Source: Field Survey, 2000

The respondents as summarised in Table 4.11 cited twelve main categories of constraints. In considering the frequency in the responses as well as the ranking of importance by the respondents, the problem of inadequate funding emerged as the biggest constraint in biotechnology R&D. Government resources were limited and as shown in Table 4.6, they were usually complementary to donor funding. Donor funding was also not inexhaustible and was usually difficult to access. The inadequacy of funds related also to the problem of lack of equipment, which was the second most important constraint. Some of the equipment were expensive to import (e.g. autoclaves, PCRs, and sequencers) and usually foreign donors donated them to the institutions. The third most important problem was that of supply of reagents. For this to emerge at this level of importance showed the sensitivity of reagent supply to the logistical arrangements in biotechnology R&D. Reagents such as the enzymes for molecular biology research were easily destroyed if not handled properly. They had to be stored under controlled conditions and usually this was not done as they came through customs at the ports. They had to be imported because they were generally not available in the country. This particular problem is also a reflection on how economic and social-cultural practices could constitute constraints in biotechnology development.

The other problems especially that of transport (4th) and inadequacy of laboratory infrastructure (5th) again referred to the sensitivity of biotechnology R&D to situational conditions. The extensive inter-institutional collaboration meant that transport must be available for trips to the respective institutions. However, some of the institutions were not well endowed with the necessary logistics. The problems of laboratories also related to the need for a certain basic level of infrastructure for meaningful biotechnology R&D. Air-conditioning and indeed controlled environment for research was vital for certain types of biotechnology work. For example, tissue culture has to be done in an environment free from contaminants. However, in some of the institutions listed in table 4.1, such fundamental requirements could not be fulfilled.

4.3.6 Approach to Project Implementation

In 24 out of the 28 projects, respondents indicated that the projects involved “team work” as against 4 “individual” projects. In the “team work” projects, two or more experts usually from different institutions collaborated in the initiation and implementation of the projects. In the case of “individual” projects, there was a sole initiator and executor. Apparently, the team approach to project implementation was in the best interest of the country as it utilised as much of the expertise as available. That is not to say that they were no constraints. Interviews with those involved with the research teams suggested that this approach could be sources of delays in project implementation especially as team members needed to travel from far to meet and get the project going. There could also be members who might not be as committed as they should.

4.3.7 Diffusion of Research Results

Table 4.12 Diffusion of Research Results

Diffusion Mechanism	Number of Projects*
Reports to Ministries, Department and Agencies	15
Academic journals	19
Mass media	9
In-house business unit	4
Patent/ IPR Applications	0
Conferences/ Workshops/ Meetings	23
Formal networks	5
Reports to donors	16
Reports to private sector organisations	6

Source: Field Survey, 2000; *Many indicated more than one mechanism

The mechanisms for diffusion of outputs from the projects are important for the utilisation of the results. Table 4.12 indicates that outputs from the projects so far were "paper" outputs that were disseminated to the peers of the researchers through journals, conferences and meetings and to the ministries and the funding agencies. Dissemination through presentations at conferences, workshops and meetings had the highest with 23 frequencies. Academic journals had the second highest with 19 frequencies and reports to the ministries, departments and agencies (MDAs) the third highest of 15 frequencies.

It is significant to note that none cited patent or any intellectual property right as a means of diffusion of research results. The capacity of researchers to use the patent regime, which in Ghana is operated under the Ghana Patent Law 1992, is an indication of their vibrancy and competence. It is also an indication of the recognition of the economic importance of the outputs from their research activities and the desire to exploit that potential through intellectual property. That no single biotechnology product has been patented yet indicates the distance of the local researchers from the frontiers of technology. The lack of patents from local researchers should be a source of worry for all stakeholders in Ghana's R&D generally and biotechnology development specifically. Apart from the Ghana Patent Law of 1992, which empowers the Registrar-General to operate the national patent system, there is also another avenue for patenting through the African Regional Industrial Property Organisation (ARIPO) based in Harare. Yet another avenue for patenting is the International Patent System based at the World Intellectual Property Organisation (WIPO) in Geneva. Local researchers can access both the ARIPO and WIPO systems through the Registrar-General's Office in Accra. An interview at the Registrar-General's Office showed that at present only about an average of three patent applications are made in a year in Ghana, compared to over one million every year worldwide. It brings into sharp relief the country's low scientific and technological capacity relative to the state of the art. Clearly there is the urgent need to strengthen the capacity given the fact that the R&D institutions constitute the knowledge bases from which the innovations flow. In the specific case of biotechnology, the global trend is the use of intellectual property rights to establish ownership over innovations and patents are becoming major indicators of the biotechnological capacity.

Reports to private sector organisations (e.g. farmers and industrialists) who constitute a major stakeholder community scored only 6 frequencies. Even as projects are in their implementation phases, one would expect a more proactive linkage for a more effective delivery of project outputs. From another angle, the paper outputs are only to be expected given that the primary concern of every researcher is to advance professionally and in the academic world, advancement is predicated on publication. An aspect of the issue, which was not investigated further, was the kinds of outlets the researchers use for the publications. There are international journals which commands respect among peers. When researchers in Ghana are publishing, it contributes to enhancing the country's status in knowledge generation. However, should publications be in only the lesser-known journals, not much academic esteem comes with them. It may be interesting to find out the nature and quality of the publications of the research corps to determine Ghana's contribution to the global knowledge in this area.

Besides, for the fact that most of the projects were on going, one could expect that reporting to the sponsoring agents such as the donors and government would become major preoccupations. Also, providing information to the general public through the mass media had not been emphasised. Nevertheless, it is important that the necessary linkages have to be established to the private sector users particularly the farmers that will eventually use the outputs, through the farmers' associations. It appears that this is not being done.

4.4 Technoware

The physical facilities form an important component in the technological capacity since without these, there can be no outputs. The survey aimed at assessing the kinds of physical facilities available and the extent to which they provided impetus for biotechnology applications in the respective institutions.

4.4.1 Biotechnology Institutions

There are two main types of laboratories, which all biotechnology institutions need to have depending on their functions to enhance research and teaching. These are laboratories for tissue or cell culture and molecular biology. As shown in chapter two, the key techniques of modern biotechnology are recombinant DNA technology, the production of monoclonal antibodies and micro-propagation. The provision of these laboratories is crucial for the strategies for biotechnology development in the country.

The survey of biotechnology institutions was primarily limited to the National Agricultural Research System comprising the research institutes and the faculties of agriculture of the universities. The survey aimed at finding out the institutions that had capacity for plant biotechnology research, the types of research activities the institutions were engaged in and the nature of the research capacity. The following data were obtained as in Table 4.13.

Table 4.13 Institutions with Plant Biotechnological Capacity

Institution	Tissue Culture	Molecular Biology
Crops Research Institute	+++	0
Forest Research Institute of Ghana	++	0
Savanna Agric. Research Institute	++	0
Crop Science Dept., KNUST	+++	0
Crop Science Dept., Legon	++	+++
BNARI, GAEC	+++	++
Botany Dept, Legon	+++	0
Biological Science Dept., KNUST	0	++
Botany Dept, U.C.C.	+++	0
Crop Science Dept., U.C.C.	++	0
Oil Palm Research Institute	0	+++
Plant Genetic Resources Centre	0	0
Soil Research Institute	+++	0
Cocoa Research Institute	+++	+++

Source: Field Survey, 2000

Notes:
+++ - Trained researchers and functional laboratory
++ - Trained researchers without functional laboratory
+ - Laboratory without trained researchers
0 - No trained researchers and no laboratory

Table 4.13 shows that only two institutions had molecular biology laboratories operating with the requisite human resource (as of 2000). In this regard these institutions (namely the Crops Science Department of the University of Ghana and CRIG) have some capacity for R&D in genetic transformation. Most of the institutions have laboratories for tissue culture but even with this, four institutions have trained manpower but without the laboratory to work with. Most of the institutions do not have laboratories for molecular biology research, which is what is required for high-level biotechnology - specifically genetic engineering. Of the fourteen institutions listed, the Plant Genetic Resource Centre neither has the full complement of biotechnology expertise or any of the two types of laboratory facilities. Many of them have neither laboratories nor trained researchers. It is worth noting that there are degrees of adequacy in the laboratory facilities given the range of equipment and the levels of sophistication in the equipment. Thus the sophistication of the laboratories supports the types of biotechnology activities that are carried out.

The data also shows that there are institutions with the trained manpower but without the laboratory facilities. Even for tissue culture, in institutions such as FORIG, SARI and Crops Science Department of University of Cape Coast, there are no laboratories for the available trained manpower (as of the time the survey was carried out in 2000).

The lack of laboratory facilities in the university departments shows the under-resourced nature of the universities. These are departments that run courses in their respective areas up to doctoral level. For a modern science such as biotechnology, these facilities should have been available for teaching-learning activities and research.

4.4.2 Physical Facilities for Biotechnology R&D

An important component of the biotechnology capacity is the technoware. The physical facilities making up the technoware make possible the various kinds of activities that the human resources perform. It was found out that the most pervasive and fundamental of biotechnology activities was tissue culturing. Therefore, an inventory of the tissue culture facilities available in the various institutions was undertaken.

Tissue culture is the production of whole plants from minute tissues of the plant, such as from the apical portions of the shoot. The production must be done in a sterile environment. For tissue culture there are the core facilities, including the laminar flow hood, sterilisation equipment, autoclaves, growth cabinets or growth rooms and ovens. The laminar flow is the table at which the culturing is done and it is equipped with a system for filtering the air from the environment in which the culturing is being done. The filters are changed from time to time and therefore filters constitute part of the consumable supplies of a tissue culture laboratory.

Since a sterile environment is the key to tissue culturing, sterilisation equipment and an autoclave are important equipment. The former has beads in its central component for dry heating to sterilise some of the instruments. The latter uses wet heating for the sterilisation process. The laboratories are also equipped with ovens e.g. the hot air electrical oven and the microwave. They perform the same function. A growth cabinet simulates the controlled condition of a growth room on a much smaller scale. Where there is no growth room, it is the growth cabinet that takes on the function of maintaining the cultured tissue in the conditioned and sterile environment for it to develop. A growth room enables several hundreds of tissue-cultured materials to be developed at one time whereas the growth cabinet accommodates only a hundred or two hundred at a time depending on its size.

To maintain the prescribed environmental conditions for the cultures, the laboratories have air-conditioners and electrical panels to control the temperature and lighting respectively. Other equipment which are also necessary are shakers to ensure continuous circulation of the media round the tissue and a peristaltic dispenser to fill up the media vessels with specificity and speed. Microscopes, refrigerators and computers are some of the equipment that tissue culture laboratories must have to enable work to be done scientifically.

Aside these equipment, the laboratories establish supply lines for consumables such as surgical gloves, surgical blades, flow hood filters and reagents. These are some of the indispensable supplies that laboratories must make arrangements for to operate efficiently. Table 14 below shows a summary of the state of facilities in the institutions surveyed.

Table 4.14 Tissue Culture Facilities in Biotechnology Institutions

Equipment and Supplies	CRIG	Bot. Legon	CRI, CSIR	Bot. U.C.C.	BNARI
A. Key Equipment and Supplies					
Peristaltic dispenser (vacuum pump)	2	1		(1)	1
Laminar flow hood	2	2	2	2	5
Growth cabinets (220-240v)	2	3	1	1	2
3-tiered gyrotary shaker(250ml)	1			1	2
3-tiered gyrotary shaker (500ml)	1	2	2		
Magenta vessels (petri dishes)	150	100		50	1000
Double distilled waterstill (240v)	1		1		2
(Distillation plant)				1	
Sterilisation equipment (glass/hot	1				4
beads)	1	1	1		3
Microscopes (512) and accessories	2	1	1	1	2
Refrigerators	1		1	(2)	2(1)
Microwave oven (electrical oven)	1	1	2		
Pipette washer and rinser	2 boxes	1 box		<1pack	4boxes
Surgical blades	7			5	
Pre filters for flow hood	2			2	5
Autoclave	4	2		1	2
Magnetic stirrer hot plate	1	1			3
PH meter (electrode stand and arm)		1			
Jiffy peats pellets		1			
Sealing machine		1			
Sprayers		2			
Trolleys		4			
Markers				2	
Hardening trays		4		1	
Thermohydrographs				1	
Ice maker machine				1	
Gene gun					
B. Other Equipment	1	1		1	3
Computers and accessories	1			1	1
UPS equipment	1	1		1	1
Generator*	6	4		1	4
Air conditioners					
C. Farm Facilities	1000	1	100	10	200
Farmland (acres)*	1		1		1
Irrigation system *	6		4		
Tractor and accessories*	1	1	1	1	1
Nursery (including screenhouse)*					

Source: Field Survey, 2000; Note * Not exclusive for the use of tissue culture laboratory

4.4.3. Modern Biotechnology Techniques

Table 4.15 Modern Biotechnology Techniques

Biotechnology Technique	Frequency Cited
Tissue culture (e.g. somatic embryogenesis)	13
Molecular techniques including:	
■ Polymerase chain reaction (PCR)	7
■ Enzyme-linked immunosorbent assay (ELISA)	3
■ Restricted Fragment Length Polymorphism (RFLP)	3
■ Random Amplified Polymorphic DNA (RAPD)	3
Extraction of DNA	7
Electrophoresis/ DNA fingerprinting	6
Hybridisation/ protoplast fusion	3
DNA sequencing	2
Bombardment using gene gun	1

Source: Field Survey, 2000

In the survey it was found that molecular biology work was rather low in biotechnology R&D in Ghana. Nevertheless, many of the basic techniques had become routine in the institutions where molecular work was going on e.g. at Crop Science Department of the University of Ghana and the Cocoa Research Institute of Ghana. Table 4.15 provides a listing of some of the techniques listed by the respondents. Probably the most interesting on the list was the plant cell bombardment for the insertion of specific genes. This was one of the techniques for the transformation of crops into their transgenic varieties. In this specific case, the aim was to produce virus-resistant and protein enriched tubers for local cultivation and it was being done at the Botany Department of the University of Cape Coast. But this was at the initial stage and no concrete results had been obtained nor disseminated yet.

4.5 Inforware - The Information System for Biotechnology Development

The key elements of an information system are facilities for information assembling and delivery in the form of a library, databases and networks and the human resources to carry out information functions. For biotechnology research and development in particular, the libraries in the universities and research institutes are the main sources of information. These are however handicapped in supporting serious biotechnology activities. The total science and technology titles in the five public universities will not be up to 20,000. In the specific area of crop agriculture, the total number of titles is less than 3,000 (Personal Communication, 2000). The value of literature is however in its currency. Most of the titles were more than ten years old. Many journals and periodicals, the backbone of scientific enterprise and research, were no more subscribed to due to lack of funds.

The problem would have been less serious if there were an effective access to the Internet, which had become probably the most important means of obtaining current information. Access to the Internet for most biotechnology workers of all categories was very limited. Of the 13 institutions listed in table 4.1 above, only five as of 2000 had Internet connectivity. In all of these institutions the connection was made to the institute's computer room for the general use of all researchers. The major shortcoming of the information system for biotechnology development was the poor and outmoded infrastructure.

The modalities for networking and linkages through the organisation of seminars and workshops are quite an important part of the information system. Scientists and other stakeholders had fora to exchange ideas and were abreast with what was going on in the country. Unfortunately, due to the inadequacy of funds, seminars and workshops were not as common occurrences as desired.

Local publications on Biotechnology were also not available. Under the Biotechnology Development Programme, the *Biotech.Ghana* was launched. This was a newsletter, which STEPRI published in collaboration with the GSES of the University of Strathclyde with sponsorship from the DFID. Unfortunately with the ending of the programme in 2000, funding for publishing also came to an end. There were a few electronic publications that were sent to specific individuals and institutions. The *CropBiotech Net* which originates from the International Service for the Acquisition and Application of Ag-biotechnology (ISAAA) provided regular updates of developments on biotechnology in a variety of areas - biosafety, innovations, country activities, etc.

In discussing the inforware or the informational capacity of a country, an important area is the area of bioinformatics, which is the application of information technology to analyse and manage large data sets resulting from gene sequencing and related techniques (Pongor *et al*, 1999, pp.10-13). Two broad issues arise. There is the issue of the use or application of the generated information and there is the issue of the ability to generate information especially the information of relevance to the country. Bioinformatics has in recent times become indispensable for biotechnology development given the fact that the innovations in biotechnology and, to be precise genetic engineering, is information-based and such information is computer-generated. It has given rise to what is usually referred to as genomics (Pereira, 1999, p.5). Market analysts estimated that the commercial bioinformatics market in 1997 came to US$ 500 million, spent by various industries on bioinformatics staff, data, software and hardware resources and might have doubled in 1999 (Pongor *et al*, 1999, p.10).

There are two levels of access to computerised biological information just as there are two basic types of biological information. There is the information generated within the biotechnology institution and which must be available to the relevant scientists. Such access may not necessarily require the use of a computer even though it may be expedient. But there is also that information in cyberspace that is of importance for the scientist and which must be accessed with information technology. Access then comes at two main levels. There is the ordinary physical access granted by a computer with Internet connectivity and there is also the access to the key sources of information relevant to the work of the scientists. With regard to the latter, there are public bioinformatics resources, such as databanks and software tools that are crucial for biotechnology projects available on the Internet at no cost. These include bioinformatics resources being updated and managed under the auspices of institutions in the developed countries such as the European Bioinformatics Institute (EBI, U.K.), the National Centre for Biotechnology Information (NCBI) of the National Institute of Health (NIH of the U.S.A.) and the DNA Databank of Japan (DDBJ). However there are also important online databases that one has to pay for before access is granted. More importantly, the practical aspects of bioinformatics, which relate to industrial applications, fall in the proprietary domain. So that whereas most of the bioinformatics knowledge such as the information about sequences of genes, the algorithms and software source codes are freely accessible, the application of such knowledge which is of the practical nature is protected (Pongor *et al*, 1999).

Often the scientists in Ghana do not have that kind of access, as funds are not available to pay for online searches in proprietary databases. Even at the access level of Internet connectivity, most researchers did not have direct access in their laboratories or offices. However, the key issue is assuming there was access to the Internet at the two identifiable levels, would Ghana as a nation have the full benefit of the immense knowledge on the Internet? Many beneficial genes and the genomes of important research used in biotechnology research such as *Escherichia coli*, *Agrobacterium* and tobacco have been mapped. The mapping of economically important crops is continuing. The complete genome of rice has been completed. Even some portions of the map of the human genome are available on the Internet. To what extent has this got meaning to the scientist in Ghana? It is an important question, which raises again the issues of the currency of skills and the absorptive abilities of scientists in new knowledge.

The issue of access to information and the issue of currency of information are inter-related. Access and currency are key determinants of the value of information and any information system needs to enhance their status. Generally the libraries in the universities and the research institutes are making efforts to improve on facilities for access, assembling and delivering of information through computerisation and Internet connectivity. Beyond this, databases are being set up and the provision of service is being enhanced. For example, the Institute for Scientific and Technological Information (INSTI) has in collaboration with the Technical Centre for Agricultural and Rural Cooperation (CTA) launched The Essential Electronic Agricultural Library (TEEAL) and the Ghana Agricultural Research Information (GHAGRI) database. The TEEAL is a system for providing up to date agricultural information to users. The information is stored in sets of CD-ROMs and at the library users are able to conduct searches for the relevant information. CTA provided funding for the delivery of the sets of CD-ROM for the period 1998-2000. The GHAGRI is a database on agricultural research in Ghana, contact persons and research institutions. Both informational facilities are being operated under the Ghana Agricultural Information Service (GAINS). An assessment of a Question and Answer Service (QAS) initiated in March 2000 in connection with the use of the TEEAL and GHAGRI gave an indication of the use of the service and its potential. See Table 4.16 below.

Table 4.16 Users of Ghana-QAS: March - December 2000

User Category	Number of Users	Percentage
Researcher	115	35.6
Lecturer/ Teacher	47	14.6
Consultant	4	1.2
Librarian/ Archivist	6	1.9
Student	113	34.9
Extension Officer	8	2.5
Policy Maker	2	0.6
Planner	8	2.5
Farmer	18	5.6
Other	2	0.6
Total	323	100

Source: GAINSNEWS, 2001

The target of 150 information searches in a year was exceeded in the first quarter and the demand for the service was of the order of about 600% of the anticipated annual (INSTI, 2001). From Table 4.16 above, researchers are the key patrons making about 35.6% of the total queries. Students gave the second highest with 34.9%. In the context of this thesis, the low percentage scored by farmers is an indication that the informational resource may not be oriented in a manner to enable farmers to benefit. Fortunately, in the second phase of the project beginning 2002, there would be efforts to address the information gap relating to farmers. In reality, one cannot expect rural farmers to patronise TEEAL, GHAGRI or use Ghana-QAS as an information source for their farming. The location of the service in Accra clearly puts these services out of their reach. There is also an issue of the relevance of the information.

Fortunately, these services are being re-formatted. Repackaged information from the TEEAL would be mass communicated to farmers through agricultural programmes particularly on some of the local FM stations. However, a key strategy is to sensitise agricultural extension agents to the benefits in the use of the TEEAL for farming activities and to encourage them to make use of the service (Personal Communication, 2002). In 2002, INASP and DANIDA paid a one-year subscription for the CSIR research institutes to access 320 scientific, technical, veterinary and medical journals available on the relevant website (URL: http://www.idealibrary.com). This is an important means of making available new knowledge to the potential users in the scientific institutions.

The crucial problem with the information system is the high investment requirement, which does not fit into the prevailing scheme of demand-driven services, where even service-oriented institutions such as INSTI have to develop their potential for commercialisation. INSTI is the main national institution established for the provision of scientific and technological information. There seems to be no market for the kinds of information service it is delivering. For example, for the year 2000 its total revenue generated from Internet access, CD-ROM searches and other non-information activities came to a total of 43.436 million cedis against an operating cost for delivering those services of 28.852 million cedis (INSTI, 2001, pp.22-35). In the meantime, the personal emoluments of the staff of the Library and Documentation Division, which provided the information services was 204.254 million cedis (ibid). The cost to maintain the staff along is at least 15 times the profit made. The point must be emphasised that information and more specifically, scientific and technological information does not attract the premium it deserves. Therefore the principles for delivery of this service to the public cannot be market-related. At least for now, government must make the necessary investments to build the information system not only at INSTI but in the universities as well.

CHAPTER 5

ASSESSMENT OF DEMAND FOR BIOTECHNOLOGY PRODUCTS – A CASE STUDY OF FARMERS IN THE NEW JUABEN DISTRICT

5.1 Introduction

This chapter presents results of the case study conducted in the New Juaben District for an in-depth examination of the realistic conditions of farmers as users of the results of biotechnology research in crop agriculture. The research extended to the farming constraints, expectations, access to scientific information and knowledge and the factors precipitating success or failure. The chapter attempts to juxtapose the issues to highlight the lessons for creating a bridge between the key actors on the supply and demand sides of innovation and technology development.

The human population of the New Juaben District is 139,370 (Ghana Statistical Service, 2000a, p.18). The estimated number of farmers in the New Juaben District was 4,000 (Personal Communication, 2000). However for this study, the Agricultural Extension Assistants (AEAs) in the district were only able to list 1,200 farmers for random sampling. The results in this chapter were drawn from the questionnaires administered to 295 farmers in the selected sample. Using the SPSS computer software, the variables coded included age, sex, education, number of years experience in farming, types of crops cultivated, total acreage, problems with crops, estimated annual profits, use of scientific inputs (namely fertilizers, pesticides and hybrid planting materials), sources of information on agricultural technologies. Table 5.1 presents a summary of the number of farmers sampled from the various villages in the New Juaben District. The differences in size of the villages account for the variation in number of respondents for the villages.

Table 5.1: Number of Farmer Respondents By Villages

Village	Number	Village	Number		Number
Aboabo	4	Jumapo	12	Oti Kwame	3
Abotanso	5	Ketenkle	16	Oyoko	16
Ada-Zongo	5	Kwadwotenten	18	Pipeline	7
Afiafi	16	Kwakyekrom	10	Sikorkor	21
Akwadum	19	Kwame Gyan	2	Suhyen	12
Akyekyeso	6	New Zongo	1	Trom-Nyerede	18
Apenkwa	5	Ntronang	25	Twapease	3
Asarekrom	3	Nyamekrom	11	Waterworks	7
Asokore	15	Obo-Nkwanta	1	Yaafiakrom	7
Effiduase	11	Obuotabiri	7	Yakoma	9
Sub-total	89	Sub-total	103	Sub-total	103

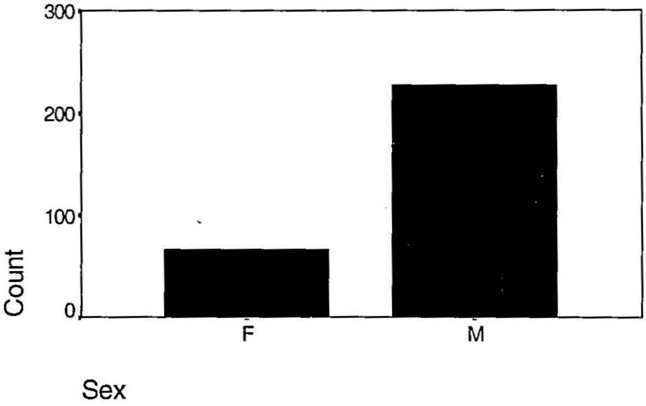
Grand Total = 295

Source: Field Survey, 2001

5.2 Farmers' Profile

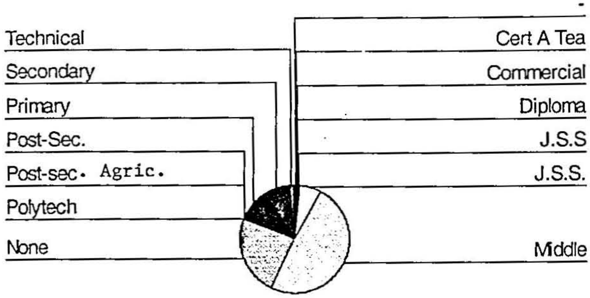
Figure 5.1 depicts that there is a dominance of male respondents. 22.7% of the respondents are females and 77.3 are males. This does not conform to the known statistics that women constitute about 52% of the agricultural labour force and produce 70% of subsistence crops (Duncan, 1997). But it must be mentioned that this is mainly on account of the sampling frame, which presented more male farmers than females. It is possible that there are more female farmers in the district than indicated and that the extension visits of the AEAs were biased for certain reasons in favour of males. However, the assumption on which this study proceeded was that, the sex representation possibly reflected the farming population that benefited mostly from extension services in the district. Extension service, or more precisely the mechanism of linking the scientific community with the farmers with innovations, was a point of interest in the research. Nevertheless, a further study may need to be done to find out whether in reality there were more women farmers and why they seemed to be excluded from the formal extension service. It is obviously of interest given the growing attention to gender issues in development research.

Figure 5.1: Distribution of Farmer Respondents by Sex



Source: Based on Field Survey, 2001

Figure 5.2: Distribution of Farmer Respondents by Educational Status



Source: Based on Field Survey, 2001

About a quarter of the farmers had no education. This was reflective of the national situation in which adult literacy rate (1997) was 66.4% (UNDP, 2001, p.105). Most of the farmers (48%) had middle elementary school education. Only about 25% of the sample had, had secondary or post-secondary education including polytechnic, technical and teacher training education. The results depicted a relatively low level of education of the farmers in the sample (Ghana Statistical Service, 2000b). This was very much illustrative of the national situation where farmers at the subsistence level generally had minimal education. It is an important factor to note in the design of policy interventions meant to enhance farming activities and in the strategies to reach farmers with innovations.

The age distribution of the farmers in the sample presents an issue of the succession of farmers by the new generation. The age ranged from a minimum of 18 years to a maximum of 85 years. (See table 5.2 below showing cumulative frequency) However, nearly 40% of the farmers were above 50 years and only about 40% were below 40 years. The mean age was 46.6 years with a standard deviation of 14.52. Obviously, this shows an unhealthy prospect for the future of farming, as it appears to support the notion that the youth are abandoning farming as an occupation. There may be several reasons why the youth may be abandoning farming and there may be several options for reversing the trend. A major option has to do with creating the conditions for making farming a rewarding venture and overcoming the numerous constraints that traditional farmers have to contend with. To this end, the generation and provision of technologies to enhance production are very vital. The age factor is important also because in the transfer of innovations to farmers the older people are less predisposed to change, which is implicit in the process of adopting technologies. A more youthful farming community will facilitate the transfer of technologies more easily.

Table 5.2: Frequency of Age of Farmers

Age (years)	Frequency	Percentage (%)	Cumulative Frequency (%)
20 and below	2	0.7	0.7
30 and below	43	14.6	15.3
40 and below	73	24.8	40.1
50 and below	60	20.4	60.5
60 and below	64	21.8	82.3
70 and below	35	11.9	94.2
80 and below	14	4.8	99.0
90 and below	4	1	100
Total	295	100	100

Source: Field Survey, 2001

5.3 Crops Grown by the Farmers

The farmers grow both food and cash crops. Usually, the farmer grows more than one crop at the same time. From the sample, the average number of crops grown by the farmer was four crops or to be precise, 3.68 with a standard deviation of 1.1. The minimum was one and maximum was six. Inter-cropping is a typical approach to farming in the traditional context and it is a factor to consider when extending modern biotechnological innovation to farmers because one has to be sure of its influence on the crops over time. There is the issue of how the biotechnological innovation applied to one crop can affect the other or even other genetic resources in the farm ecosystem. For example, one of the risks in planting genetically modified crops is non-target impact (Williamson, 1996). A crop may be modified to be herbicide resistant in order that more of the herbicide is used for greater effect. However, in a multi-crop environment such application may be disastrous with other crops being affected. The transition of farming into GM crops will obviously require a system transformed in the locality into single crop farming. It is a situation that may have unfavourable consequences since farmers grow many crops on the farms.

To indicate the relative importance of the crops, farmers were asked to mention three crops grown in order of importance. Of the 20 crops mentioned as the best three crops, maize was the most widely grown. The percentage of the farmers citing maize, as a first crop was 64.4% and 21% of the farmers cited it as the second best crop. Cassava was the second most important crop as almost 12% cited it as the best crop (ranking third) and 63.4 % cited it as the second best crop (ranking first). Cocoa also placed second by the ranking. It suggests that by ranking, the three most important crops for the farmers are maize, cassava and cocoa. In December 1999, a National Stakeholders' Conference carried out a priority-setting exercise for biotechnology application and development in the areas of agriculture and health. Cassava, maize and cocoa came out as the three most important crops that biotechnology Research and Development should focus on (Essegbey *et al*, 1999; p.84). The crops listed here also fall into the categories of crops that researchers are working on. (See table 4.2 in the previous chapter). An attempt was made to match the list of crops worked on by the scientists (on the supply side) with the crops that farmers grow on the demand side using the ranking as well as the list of crops proposed by the stakeholders.

The issue therefore is not whether scientists in Ghana are working on real farmers' needs - because they are - but whether farmers are actually deriving the benefits of their research in terms of enabling them overcome their farming constraints. Indeed in the national scheme of crop R&D, certain crops have been prioritised so highly that research institutes have been established to focus on them. The CRIG focuses on cocoa, coffee and recently shea nut and cola have been added to the mandate. OPRI also focuses on oil palm and coconut. More pertinent to the subject of the thesis is whether farmers can derive or are deriving benefits from biotechnology applications and development in crop agriculture; whether the R&D institutions are extending innovations to the farmers that address their farming constraints.

5.4 Problems in Crop Production

The farmers' responses to the question of what problems militate against their farming shows that, they have to contend with crop diseases, pests, low fertility of the land and other unfavourable climactic factors. The problems listed are typical of the tropics. Insect pest infestation, which accounted for about 55% of the cases, had been so chronic a problem that insecticides constituted the bulk of agro-chemicals imported into the country. For example between 1995 and 1998, of the total of 993 metric tonnes of agro-chemicals officially imported into Ghana, 68.8% were insecticides. (See Table 5.3 below) Insect infestation of crops was a pervasive problem, which was exacerbated by the incidence of insect resistance to chemicals. Whatever it is, the problem has to be effectively dealt with to enhance farmers' productivity. The problem of crop diseases (to which insects acting as vectors contributed) was also a key problem facing farmers, which also needed attention.

Table 5.3: Average Official Agro-Chemical Imports (MT) - 1995-1998

Agro-chemical group	Quantity (MT)	Percentage of total
Insecticides	683	68.8
Fungicides	159	16
Herbicides	125	12.6
Nematicides	24	2.4
Total	993	100

Source: MOFA (2001) p.29

From the study, it appeared that the problem of poor soil was not that prominent in comparison with the others. However, one might look at it in association with the problem of low yield - though poor soils were not exclusively the causes of low yields.

The direct solution was the application of fertilizers. Fertilizer imports had fluctuated in recent years following the austere free market conditions. (See Table 5.4 below.) Farmers' use of fertilizers had suffered since the liberalisation of the economy. For example, it was estimated that cereals cultivated in the northern regions accounted for almost half of the annual fertilizer consumption before 1991 but now demand in this region had become negligible (FAO, 1999).

Table 5.4: Fertilizer Imports 1990-1999 ('000 Mt)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Total	43.85	-	29.40	20.16	24.06	28.14	19.84	56.16	42.31	21.99

Source: Derived from MOFA (2001), p.28

From 1990 to 1999, the average total fertilizer imports per year, including ammonium phosphate, urea and NPK was less than 30,000mt. Not surprisingly, Ghana's use of mineral fertilizers averaged less than 6kg/ha compared with 97kg/ha worldwide (FAO, 1999; p.9). Current production of main food crops in Ghana reduces the nitrogen and phosphate content in the soil by an estimated 70,000 and 25,000 tonnes annually which requires an annual fertilizer consumption of about 400,000 tonnes (FAO, 1999; p.9). The situation however cannot improve so long as analysis of the fertilizer-to-crop price ratio shows that the use of fertilizer is less profitable with fertilizer prices increasing faster than crop prices (Gerner et al 1995). Farmer's use of fertilizers is therefore at best half-hearted and at worst non-existent.

Other problems, which surfaced as militating against the cultivation of the crops were problems with nematodes, mistletoes, mammals (i.e. grasscutters, rats and squirrels), weeds, storage, winds, droughts, floods and birds. The problem of mammals seemed to be rather pronounced among this set of 'lesser' problems and it was something very much beyond the scope of biotechnology. But some of these problems such as those of storage, fungus, nematodes and droughts were within the scope of biotechnology applications. Some solutions were already available to farmers in other parts of the world while attempts were also going on to address some of these other problems. For example, the genetically modified tomato labelled Flavr-Savr has a significantly extended shelf life. Crops modified with the Bt gene spliced from *Bacillus thuringiensis* produce their own toxins to fight against pests. Monsanto produced the Bt maize to counter the problem of stemborers, which affect low yields and the Bt cotton against the bollworm. Generally, no serious genetic engineering or crop transformation was going on locally. However, the experimental transformation of cassava to enhance protein content using micro-projectile bombardment of gold particles coated with DNA at the Botany Department of the University of Cape Coast in collaboration with Eastern Washington University showed that there was the potential to address the farmers concern.

5.5 Farmers' Income from Farming

Income is an indicator of the gains from the farming occupations and to significant extent an indicator of productivity. It also represents the farmers' ability to adopt scientific inputs, which apparently come at a cost. At the root of the farmers' ability to adopt biotechnology innovations that address their own concerns is the issue of their income levels. From the farmers' responses, income levels were seriously low. Table 5.4 gives a summary of the indicated total annual net profits of farmers. Even though these were estimates not backed up by any verifiable evidence such as bank statements, the figures quoted gave a fair idea about the farmers' own perceptions regarding the returns they made on their farming.

Table 5.5: Farmers' Total Annual Net Profit from Farms

Amount (US$)	Frequency	% of Sample	Cumulative %
50 and below	63	33.6	33.6
51-100	71	24.3	57.9
101-150	49	16.8	74.7
151-200	19	6.5	81.2
201-250	13	4.4	85.6
251-300	16	5.5	91.1
301-350	9	3.0	94.1
351-400	1	0.3	94.4
401-450	3	1.0	95.4
451-500	2	0.7	96.1
501-550	2	0.7	96.8
551-600	2	0.7	97.5
Above 600	5	1.5	99.0
Missing	3	1.0	100
Total	295	100	

Source: Field Survey, 2001

More than 57% of the farmers' income is $100 per annum and over 81% earned up to $200 per annum. It reflected the findings of the Ghana Living Standards Survey (GLSS) that 58% of those identified as poor were from households for whom food crop cultivation was the main activity (Ghana Statistical Service, 2000b, p.13). Other results of the GLSS showed that the concentration of poverty among food farmers became much more pronounced using measures which also took account of poverty, or when extreme poverty was considered (Ghana Statistical Service, 2000b). The economic status of the farmers is important because it provides an important launch pad for government policy in addressing the demand side issues in biotechnology development. Of relevance to policy is the conclusion that the gains made in the reduction of poverty in Ghana from the level of 52% in 1991/92 to 40% in 1998/99, export farmers were among those who enjoyed the greatest gains. The incidence of poverty dropped from 64% in 1991/92 to 39% in 1998/99 for the export farmers (Ghana Statistical Service, 2000b). However, the same cannot be said for food farmers. What the field data in Table 5.4 suggest is that there is need for policy interventions to enhance the income of farmers in general in order to strengthen their capacity to adopt scientific inputs. In the context of the conceptual framework of this thesis, the strategies of building capacity for the supply of innovations must also include strategies to ensure the use of them.

5.6 Farmers' Use of Scientific Inputs

Scientific inputs are here defined as fertilizers, pesticides, weedicides and improved planting materials. The improved planting materials of hybrid seeds in themselves are biotechnology products and their adoption or use will indicate the level of demand for these products from the supply side of innovation. The demand for fertilizers and pesticides can be proxies for demand for biofertilizers and biopesticides. In the survey of the research institutions, there already is supply of improved planting materials using biotechnology techniques. There are also initiatives to supply biofertilisers. It is useful to assess demand for this in terms of farmers' propensity to adopt these biotechnology products.

It is significant that 84.7% of the farmers affirmed that they used scientific inputs in their farming activities. Only about 15% did not use these and had been relying primarily on nature to achieve their expected production levels. It had both the positive and negative implications. On one hand, there were farmers who still farmed in the truly traditional sense not using any chemical inputs. For the environmentalist, this is a positive practice. On the other hand however, this kind of farming could be least productive given the multiplicity of constraints that the farmers had to cope with and for which these scientific inputs were supposed to address. But the issue was not only whether the farmers availed themselves of these inputs at all, but also whether they were used in accordance with specification and regularity. This was important because even with the genetically modified crops, there were specifications that came with their adoption and farmers needed to adhere to these. Indeed the statistics that came with examining the use of the specific inputs suggested a certain behaviour pattern of farmers that might need to be changed to enhance the benefits of biotechnologically improved crops.

The use of improved hybrid planting materials was quite encouraging. 69.2% of the farmers always used hybrid seeds. The observed percentage exceeded the findings of Morris *et al* (1999) where 54% of farmers planted improved maize on at least one part of the farm. This was in marked contrast to the very high percentage of farmers who never used weedicides (91.2%), fertilizers (68.8%) and pesticides (43.1%). Only 18% of farmers never used hybrid crops. 9.2% of farmers used hybrids sometimes, 3.1% used it occasionally and 0.3% used it rarely. The comparison of the use of the scientific inputs is summarised in Table 5.5 below:

Table 5.6: Summary Use of Scientific Inputs by Farmers

Input	Always (%)	Sometimes (%)	Occasionally (%)	Rarely (%)	Never (%)	Total* (%)
Fertilizers	11.5	13.2	5.1	1.0	68.8	99.6
Weedicides	3.7	3.4	0.7	0.7	91.2	99.7
Pesticides	41.4	10.8	3.4	1.0	43.1	99.7
Hybrids	69.2	9.2	3.1	0.3	18.0	99.8

Source: Field Survey, 2001

The high adoption of the hybrid planting materials was due to a number of factors. In ranking order the reasons cited for the adoption of the hybrids were:

- Increase in production when used
- Better quality of harvest
- Makes farming easy (reduces drudgery)
- Reduces cost of production
- Environmental friendliness.

5.7 Gender and Use of Scientific Inputs

The study investigated the issue of gender effect on the use of scientific inputs. Farmers using any of the scientific inputs are classified as users. Using the chi-square, it tested the significance of the difference in the observation between the male and the female users and non-users of scientific inputs. The result is as presented in Table 5.6 below:

Table 5.7 Gender and the Use of Scientific Inputs

	Non-users		Users		
Gender	Observed	Expected	Observed	Expected	Total Observed
Females	16	10	51	56	67
Males	28	33	199	193	227
Total	44	43	250	249	294

Source: Based on Field Survey, 2001 (Note that total here is 294 due to one non-response for this particular question)

To test the significance of the difference between the observed results of male and female users of scientific inputs, the Chi-square test was applied as detailed below:

X-square = $Z(O - E)^2 / E$, where Z is the summation, O is the observed and E the expected.

By substitution from table 5.13 above:

X-square $= (16-10)^2 / 10 + (51-56)^2 / 56 + (28-33)^2 / 33 + (199 - 193)^2 / 193$

$= 3.6 + 0.446 + 0.76 + 0.187 = 4.993$

Hence, summation of X-square value = 4.993 (calculated value)

However, the tabulated X-square at P(0.025) = 5.02 and at P(0.010) = 6.63 (See Clarke and Cooke, 1992, p.439)

One may apply Yates' Correction for continuity with the following formula:

X^2(corrected) = Summation $(Io_1 - e_1I - 0.5)^2 / e_1 + (Io_2 - e_2I - 0.5)^2 / e_2 + \ldots$

By substitution, X2 (corrected) = 3.025 + 0.362 + 0.614 + 0.0.157 = 4.158.

In interpreting the results, one notes that at the level of significance of P(0.025), the calculated chi-square value of Yates' Correction 4.158 is less than the tabulated value of 5.02 at the degree of freedom of one. It means that there is significant difference between the observed and expected number of male and female users of scientific inputs. Apparently, gender has effect in the adoption of scientific inputs at this level of test of significance. At the higher level of test of significance i.e. P(0.010), one notes that the corrected calculated value of 4.158 is much less than the tabulated value of 6.63 suggesting that there is significant difference between the observed and expected data on male and female use of scientific inputs. Apparently, gender is a factor in the adoption of scientific inputs and male farmers seem to use scientific inputs more than their female counterparts. This has policy implications for agricultural extension services and for the transfer of technology from the scientific community to the user ends. There is need to facilitate female adoption of scientific inputs through specially designed policy interventions such as well-targeted access to information and knowledge about the scientific inputs. Obviously, there should be discriminatory opportunities to empower female farmers to use scientific inputs. In this regard there may be need for more detailed research concerning the issue of gender in the use of technologies with the view of finding out the factors militating against female use of technologies generally.

5.8 Farmers Saving Seeds

The strict traditional farming was reflected in the farmers saving seeds for planting. On one hand, it was a positive practice in terms of the potential for the conservation of indigenous germplasm. A major fallout of the Green Revolution was the threat of erosion of landraces (i.e. the indigenous species of crops) as farmers adopted the improved hybrids. For example, the penetration of the improved maize from the Ghana Grains Development Programme was 54% (Morris *et al*, 1999). With the introduction of the improved variety of Obatampa in 1992, already 20% of the total maize growing area amounting to at least 130,000 hectares had been planted with Obatampa and it was spreading at an estimated rate of about 50% per year (Twumasi-Afriyie *et al*, 1999, p.25). It is a justification for the institutionalised programmes for conservation of indigenous varieties with the establishment of the Plant Genetic Resources Centre in order to conserve the genetic resources with which further improvement of the hybrids can be made in the future. Therefore even as the adoption of hybrids is a positive development, which portends well for the generation of new technologies, steps have to be taken to protect indigenous varieties or the landraces. The other aspect of the problem of hybrid seeds is the potential for creating dependency among farmers who have to seasonally buy new seeds in order to obtain very good harvests. In the case of genetically modified seeds such as those of herbicide tolerance, the seeds have to be purchased with the respective chemicals. Naturally this increases the dependency of farmers on seed companies and has policy implications for subsistence farming.

5.9 The Sources of Information about New Technologies

The sources of information about new technologies are critical in creating demand for them. The study investigated some of the issues involved. Farmers considered the role of the Agricultural Extension Agent (AEA) as very important in the dissemination of new technologies. In the assessment of the sources of information on new technologies, the

AEAs were considered the most important. As many as 83.1% of farmers, considered the AEO the most important source of information for new technologies and scientific practices. 13.7% regarded other farmers whether as individuals or as farmer associations the most important and 3.2% regarded the mass media as the most important. It is significant to note that the scientists or researchers as a category were not mentioned as being the vital sources of information on innovation.

Indeed the study went further to probe the perceived position of the scientist on the scale of importance as source of information for farmers. In the survey, farmers were also asked to indicate their second most important source of information. According to the farmers' responses, the second most important source of information is the mass media (with 55.9% of the responses), followed by the farmers themselves (with 28.8% of the responses). The third in this ranking of importance was the AEO (with 9.2%) and then the sellers (with 3.4%). Less than 1% of the farmers even considered the scientists as the second most important source of information.

The survey went another step further to ask about the third most important source of information for the farmer. Again the ranking order was a confirmation of the previous results showing that the scientist was not really an important source of technological information for farmers. About 40% of the respondents did not indicate any third important source (as there was no obligation to do so), 21% considered the mass media to be the third most important source, the next were the farmers (17.6%), sellers (16.6) , the AEO (4.1%) and finally the researchers (0.3%).

Apparently, the role of the AEO or AEA as a channel of transmission of technological information was an important one and the findings provide a basis for policy interventions. Naturally, farmers saw the AEO as the first line of information. It underscored the need to pay attention to extension services. The appropriate manpower had to be created and the necessary logistics had to be provided to motivate extension workers. There had been a restructuring of the extension services system in Ghana aimed at a unification of the key extension systems, which operated under the Ghana Cocoa Board and the Ministry of Food and Agriculture (MOFA) respectively. Currently, one extension service system operated under the MOFA.

In the study of the farmers in the New Juaben District, it was found that the 15 operational areas of the district had to be redefined since only 10 AEOs were available. It meant that if the estimate of 4000 farmers in the district should hold, then the ratio of AEOs to farmers was 1:400. Assuming an AEO was dedicating a day to a farmer through the year seven days a week, he still would not be able to reach out to every farmer in the year. Government had made efforts to provide vital logistics such as motorbikes. But of the 10 AEOs, only five had serviceable motorbikes. As expected, the AEOs complained about low salaries and poor conditions of services. It boiled down to the issue of priorities in the process of allocation of national resources. For a typical developing country, Ghana's resources are severely limited. However, that is the more reason why the issue of scrupulous prioritisation in resource allocation is vital.

The other issue that the findings raise is the minimal importance the farmers accord the scientists as sources of information. Obviously this has to do with the weak linkage between the scientific community and the farmers, which is further discussed in the next section. However, the point is that the scientific community constitutes the central point of knowledge, which definitely is of relevance to the farmers' activities. The fact that that knowledge is not making input directly into the farmers' activities is something to worry about. But there are some explanations for this. One has to do with the institutional framework for knowledge flow from the central point to the peripheries. There is the agricultural extension system that is configured to serve as a channel for this flow. The issue is whether that system is actually an effective channel. There appears to be a vertical scientist-farmer relationship made worse by the existing channel placed between the scientists and the farmers. Current discussions on the need for reform of R&D institutions relate to the issue and this is discussed in greater depth in the subsequent section.

5.10 Linkages Between Farmers and Scientists

One may expect farmers to reach out to researchers in the R&D institutions for solutions to their problems. Farmers in the district do not do this. Of the 295 farmers interviewed, only 10 actually took the initiative to go to researchers and get them to work on their problems. There were reasons for this extremely low farmer' initiative to reach out to local scientists to solve their problems. There may be the problem of distance as the nearest research institute, the Cocoa Research Institute of Ghana (CRIG), was about 25 kilometres away in Akim Tafo. It was explained that farmers usually channelled their problems through the AEOs or brought them to the attention of the MOFA during their scheduled durbars. The officers were then to go to the appropriate scientific institution for solutions. (Personal communication, 2001) However, the very limited direct interaction between farmers and researchers highlight a weak link between the national innovation system on one hand and the innovation user end on the other hand. Perhaps to underscore the potential benefits of such interaction, nine out of the ten who went to the research institution for solution to their problems came away with "good" opinions about the scientists. Thus the case is being made for the scientists to reach out proactively to the farmers. Going back to the farmers' responses on the sources of information, one can identify a number of strategies to enable the scientist to reach out. This can be deduced from the specified sources namely:

- the AEOs (need greater interaction with farmers)
- the mass media (need enhanced farmers education programmes)
- farmers (improve interactions among farmers)
- commercial distributors of scientific inputs (need to liaise more with farmers about their products)

Local scientists need to interact more frequently with the AEOs in order to pass on their knowledge particularly on their work. It is important that for the scientists to realise that, in the existing configuration of extension services, the AEOs constitute the key conduit to reach the farmers. Seminars and workshops for the AEOs will be in the right direction. However, that should not preclude direct interaction with farmers. In fact, the direct flow of their knowledge into the farmers' activities is a necessity. More importantly, it is a means of obtaining direct feedback into their R&D activities, which can facilitate the uptake of their results. To this end, durbars with farmers, field visits and the use of demonstration farms are very much desirable for the transfer of knowledge to, and feedback from the farmers. The use of the mass media is also an important means of such transfer. Farmers' educational programmes are very vital in this direction. These are the mechanisms for changing the prevailing vertical scientist-farmer linkage to a horizontal relationship.

5.11 Government Policy

Since the launching of the Economic Recovery Programme in 1983, the country moved into a liberalised laissez faire market system. The general principle on which government fashioned its socio-economic policies was that, government should play the role of a referee rather than a player in the market place minimising the propensity for intervention. Even sectors such as agriculture, which hitherto had benefited from government subsidies, have had to adjust to the "free-fall" economic paradigm. The consequences have not been too favourable on critical areas such as returns on the labours of rural farmers as illustrated by the fall in indices of real average wholesale price.

A major avenue for assistance to farmers to enable them increase their value on their produce is for them to be provided with scientific inputs to address the constraints in their farming activities not only at the production phase but also at the post-harvest and processing phases. Biotechnology products such as biofertilisers and planting materials of crop varieties with resistance against biotic and abiotic stresses will enable better harvests and reduce spoilage.

Indeed government investment in agriculture had been shrinking over the years. From 3.5% of agriculture expenditure over total government expenditure in 1990, the percentage agriculture expenditure over total government expenditure in 2000 was 1.89%. The reduction in government's expenditure on agriculture can be explained in part by the free-market thrust in government's economic policies. However, given the role agriculture plays in the national economy and its contribution to GDP, government has to examine again its budgetary support for the sector. A major argument made against public subsidies is the fact that the prevailing world regulatory arrangements under the World Trade Organisation do not permit public subsidies in agriculture. A discussion of the regulatory provisions will be beyond the scope of the thesis but it is necessary to point out that subsidies do not come under complete prohibition. The advanced countries offer subsidies to farmers and the U.S. has currently passed a bill to support farmers with an amount of $190 billion over a ten-year timeframe. It is a question of how and in what form the subsidy is given. It is vital that government reviews its policies on subsidies for farmers in order to address some of the socio-economic constraints facing farmers.

Somehow, farmers still consider government policy generally adequate. 33.2% of the respondents consider government's agriculture policy as adequate, 61.3% of respondents consider it quite adequate and only 2.7% considers the policy inadequate. The opinions as captured here do not match with the prevailing conditions of the farmers. For example, the incomes they make from their occupations place most of them below the poverty line of a daily wage of one dollar. This may (or may not) be ascribed to government policies. Whatever be the case, the explanation of the observed data relates to the fact that the opinions may have been expressed in relation to the broader issue of government's overall performance. The question even assumes political connotations for the farmer respondent. The comments some of the farmers make at the end of the interviews buttress the point. "The government is doing well." "The agricultural inputs are available for purchase." "The agricultural officers working for the government are doing well." These comments seem to beg the issue. Do farmers really think that government policies were adequate? Or did they simply have no informed opinion? These were questions that had to be explored further.

Nevertheless, in some of the cases where respondents explained their responses, farmers said the government still maintained extension services, provided feeder roads to the villages as well as basic needs such as boreholes for safe drinking water. Whereas these may not be sound basis to assess the government's agriculture policy, it suggests that farmers' concerns go beyond their farms and that even sectorial policies need to be holistic.

CHAPTER 6

BIOTECHNOLOGY IN GHANA - TRENDS, ISSUES AND PROJECTION FOR THE FUTURE

6.1 Introduction

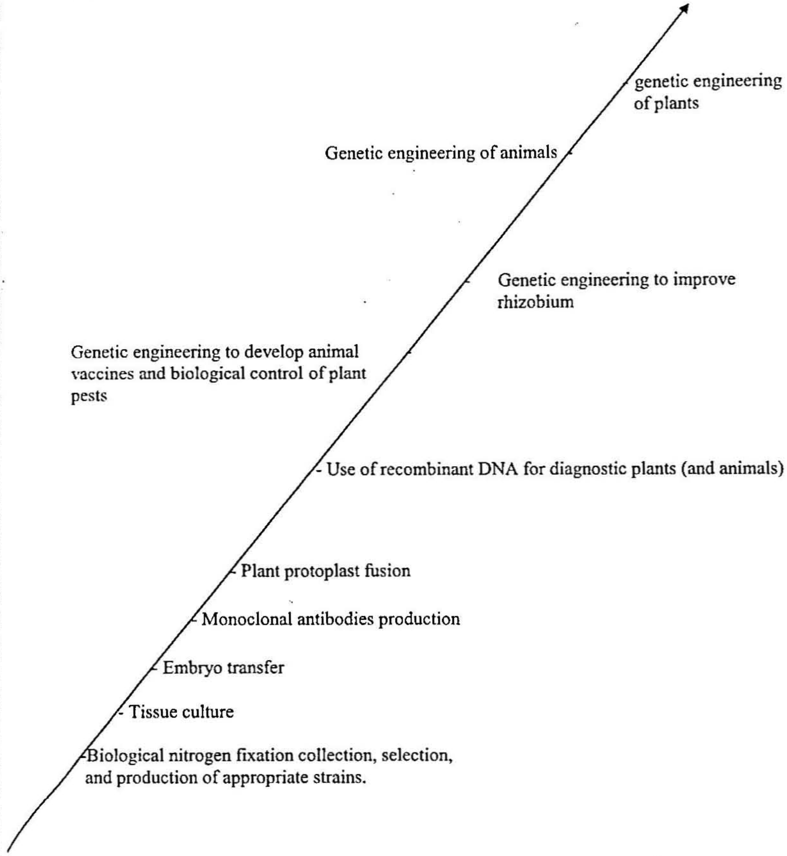
In the previous two chapters, the findings of the state of biotechnology from both the supply and demand sides of innovations were presented and discussed. This chapter will attempt to make a summary assessment of the state of biotechnology in the country, the corollary issues and make projection for the future capacity with reference to the national vision of the attainment of middle-income status by the year 2020 with emphasis on poverty reduction. It begins with a description of the functions, activities and programmes of the composite elements of the NARS, which are the knowledge centres of innovation in the country. The chapter assesses these activities vis a vis the progression of biotechnology development generally. The chapter attempts an analysis of biotechnological capacity development to attain the goals spelt out in the national development framework.

6.2 Progression of Biotechnology Advancement

Biotechnology is a spectrum of techniques, tools and processes each of, which is at a particular level of advancement. There is no gainsaying the fact that the real value of biotechnology for developing countries lies in its applicability for the exploitation of the genetic resources of these countries. A country therefore could apply and develop a particular set of techniques to address its own specified development objectives.

Therefore whereas some techniques and tools may be beyond the capacity of a given country for lack of the technoware or the humanware, other techniques and tools may be within the capacity of that country. The gradient of biotechnology - a scheme of the progression of biotechnology in a given context - provides a point of departure in analysing the state of biotechnology in Ghana and in examining the kinds of techniques and processes in application in the country (Persley *et al*. 1990).

Figure 6.1 Gradient of Biotechnology



NOTE: ⇑ increasing scientific knowledge, complexity or financial support needed;

⇒ increasing time

Source: Cited in Persley *et al* (1990)

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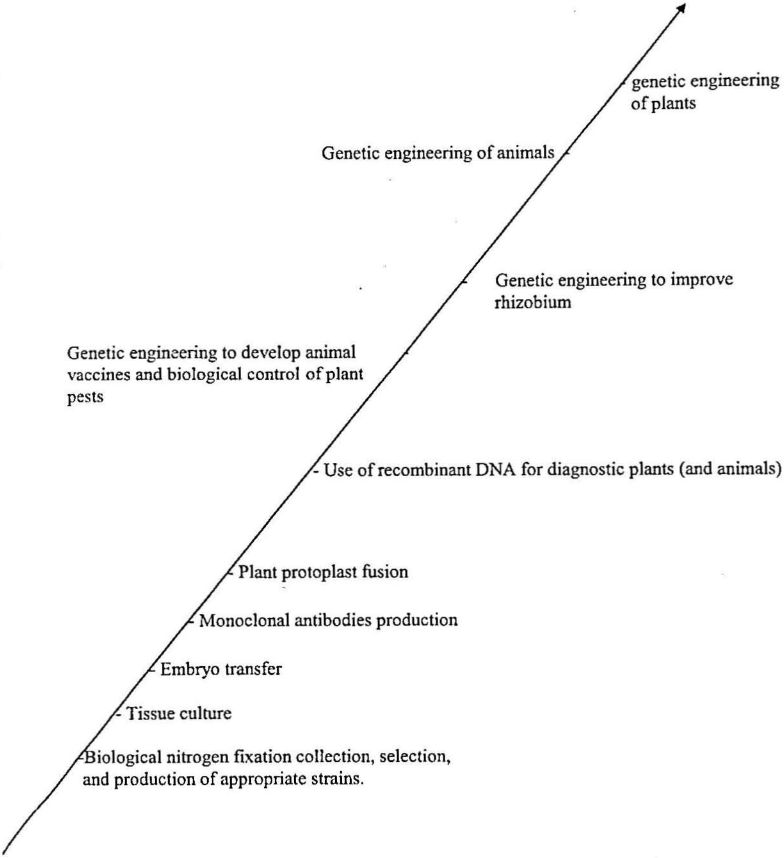

NOTE: ⇑ increasing scientific knowledge, complexity or financial support needed;

⇒ increasing time

Source: Cited in Persley *et al* (1990)

The sophistication of biotechnology in Ghana has progressed to the use of recombinant DNA for diagnostics in plants. As indicated on the gradient of biotechnology, the basic step in modern biotechnology is the screening for local rhizobium strains and the development of inoculants to enhance soil fertility. These have been part of the programmes of the Soil Research Institute and currently, inoculants are under going field trials in various ecological zones (Personal Communication, 2000). The potential for production of biofertilizers using indigenous rhizobial strains exists. However, there is need to provide resources for its actual development to the commercialisation scale for the benefit of farmers especially at a time when the high cost of chemical fertilizers are making it difficult to improve on the fertility of their farms. The case of biotechnology in Ghana illustrates the importance of entrepreneurs or the relevant actors in moving the innovation to the users.

Another biotechnology that has potential to benefit farmers is tissue culture. It is also a fairly matured technology now to the extent that planting materials e.g. plantain and bananas have been supplied to farmers. The tissue culture laboratories at BNARI, the Botany Department of the University of Ghana, CRIG and the Botany Department of the University of Cape Coast have worked on various food crops including cocoa, cassava, pineapples and vegetables. On account of, or in spite of, the maturity of tissue culture R&D, the challenge for tissue culture is three-fold namely:

- commercialisation of tissue-culture planting materials,
- application of tissue culture to other problem areas such as conservation of biodiversity,
- development of protocols for specific plants e.g. medicinal plants.

6.3 The Objectives of Biotechnology Applications in the NARS

The objectives of biotechnology applications and development in the National Agricultural Research System (NARS) are:

- the development of improved varieties of crops,
- the enhancement of soil fertility for crop production,
- the study and control of pests,
- the study and control of diseases,
- germplasm characterisation and conservation.

These objectives are being addressed through the R&D activities of the institutions of the NARS. These activities exhibit a dynamic interplay of the key components of the technoware, inforware, humanware and the organoware of the institutions. To this extent the nature and state of the activities reflect the prevailing capacity. Examining what obtains in the NARS provides a basis of determining the existing capacity and presents a basis for projections.

6.4 The Biotechnology Applications in Ghana

Table 6.1 Summary of Biotechnology Applications in Ghana

Type of Biotechnology	Institutions Involved	Remarks
Nitrogen Fixation	Soil Research Institute	Field testing of innoculants
Tissue Culture	BNARI, CRIG, Botany Dept. of U.G.and U.C.C.	Most established technique with extension of products
Embryo/ anther culture	BNARI,	Experimental
Mutagenesis	CRIG, BNARI,	Some products on tests
Monoclonal antibodies	Crops Science Dept., U.G.	For detection of causative disease agents
Marker-assisted systems	Crops Research Institute, SARI, FORIG, U.G.	Tools such as RFLP and RAPD are in routine use.
Genetic modification	U.C.C. Botany Dept.	Experimental

Source: Based on field data, 2000

In Ghana, tissue culture is also used to support molecular research into some of the problems of crop production. For example at the CRIG there is a major research effort to produce cocoa, which is resistant to the Cocoa Swollen Shoot Virus Disease (Essegbey, 1998). An aspect of the work involved the tissue culture of selected plants, irradiation to cause mutation and further selection for resistant plants, which are then micro-propagated.

One of the earliest attempts in Ghana to modify and thereby improve the genetic constitution of a crop involved the technique of mutation breeding at the CRIG. This was done in collaboration with BNARI. Mutation breeding is only a conventional technique that brings about genetic modification in a random and unpredictable manner. It does not compare with the actual techniques of genetic engineering, which involves the identification and isolation of a specific gene of an identified trait and the insertion of it in a particular crop with the view of imparting the identified trait to the crop. Genetic engineering on the other hand is a predictable and targeted technique, which is the highest point of plant biotechnology.

Marker-assisted system (MAS) refers to a set of biotechnology techniques that enable specific traits or characteristics to be marked in living organisms. A workshop was held in August 1996 at the IITA in Ibadan on DNA Marker-assisted Improvement of the Stable Crops of Sub-Saharan Africa (Crouch and Tenkouano, 1999). The workshop concluded that MAS offered considerable advantages for selecting desirable post-harvest traits for various local crops such as maize, yam and beans. But it noted that the development of DNA marker technology was both expensive and time consuming. The practical application of early molecular marker systems in plant breeding programs was considerably limited by the assay technology, which could not be applied effectively "in terms of cost and time, on the scale of modern selection programs." However, it was noted that already there was improvement of the facilitating technology at a "tremendous rate". It was possible to select from a wide range of equipment including almost completely automated throughput systems, "which could adequately deal with the genotyping of many hundreds to several thousands of individuals per day" (Crouch and Tenkouano, 1999).

The workshop on MAS discussed critically the problems facing scientists in the sub-region in the use of the technology and exchanged ideas for improvement. It noted that the choice of marker assay and the number of markers to be screened depended both on the nature of the species being studied and the type of molecular breeding approach to be followed. For example, Restriction Fragment Length Polymorphism (RFLP) was generally considered too labour intensive for large-scale routine screening. Yet given the information value of the technology, it was most preferred for some cereal systems. Microsatellite markers had also proved to be highly abundant and polymorphic in addition to being reliable and were often the assay of choice for marker assisted selection programmes. Amplified Fragment Length Polymorphism (AFLP) assays were also gaining considerable attention due to the very high number of loci that could be studied with each assay (Crouch and Tenkouano, 1999).

6.5 Production of Biofertilizers

At the Soil Research Institute, a total of 100 local strains of *Rhizobia* were isolated from cowpea nodules. Criteria for screening the strains were established. These included:

- the ability to form nodules and fix nitrogen on target legume,
- ability to compete in nodule formation with populations of Rhizobia already present in the soil,
- ability to fix nitrogen across a range of environmental conditions, and
- ability to grow well in artificial media, in inoculant carrier and in the soil.

On the gradient of biotechnology (as in Figure 6.1) production of nitrogen-fixing bacteria inoculants is assumed to be a step one in biotechnology development. It does not make this any less important than other biotechnological activities, nor any less knowledge-intensive. The process actually involved other molecular biology techniques such as PCR.

A point that has to be underscored is the inter-relatedness or complementarity of skills that runs up the gradient. The production of nitrogen-fixing inoculants however remains a step one biotechnology (in terms of the gradient) basically because the end product is of less complexity and knowledge intensity.

The complementarity of skills also manifests in terms of the physical facilities. At the University of Ghana, an Eco-laboratory had been set up and fitted with some of the needed equipment for biotechnology work. Equipment such as polymerase chain reaction (PCR) machines, autoclaves, centrifuges, fermentors and gas chromatographs were available for researchers of any discipline to use. During interviews with some of the biotechnology departments on campus, some lecturers still preferred to have their respective labs equipped for themselves. There were constraints such as the inconvenience in the moving of experimental materials in using the Eco-lab and in some cases they did not even have information about the lab. Nevertheless, the Eco-lab illustrates the concept of a Centre of Excellence in selected institutions as a means of enhancing the development of biotechnology in Ghana through the judicious application of limited resources. Nevertheless, the limitations of the concept of centres of excellence should be kept in the fore. Developing centres of excellence implies a reallocation of resource from one institution to the other and may affect the development of the institutions in terms of capacity building.

6.6 The Grains and Legumes Development Programme

Certain key projects have contributed to the enhancement of biotechnology in the country. One of such projects is the Ghana Grains Development Programme (GGDP) implemented from 1979 to 1997. The programme contributed to the development of improved varieties of some of the important staples of the people. It was aimed at developing and diffusing improved technologies for maize and grain legumes. The Crops Research Institute executed the programme with technical assistance from the International Institute of Tropical Agriculture (IITA). The Canadian International Development Agency (CIDA) and the Ghana Government provided funding. Morris *et al* (1999) conducted a survey to assess the impact of the improved maize production technologies extended to farmers during the programme. They concluded that there had been extensive adoption of three GGDP-generated technologies namely improved varieties, fertilizer recommendations and plant configurations. For example, during 1997 the total number of farmers planting the improved varieties on at least one of their maize farms was 54% and a similar proportion implemented the plant configuration. The adoption of the fertilizer regime was however only 21% (Morris *et al*, 1999). It was noted that the cost factor in fertilizer usage especially with government subsidies removed, played a significant role in the low adoption by farmers. The study showed that the adoption of improved production technology was directly influenced by three sets of factors:

- The characteristics of the technology e.g. complexity, profitability, riskiness, and compatibility with other technologies.

- Characteristics of the farming environment e.g. agro-climactic conditions, farmer knowledge and availability of physical inputs.
- Characteristics of the farmer e.g. ethnicity and culture, education and gender.

It may be said that the GGDP was successful, not only on the basis of the adoption rates of the extended technologies but also on the overall impact of the programme on grains production in the country. For example, the average production of maize per hectare was improved from 0.82 tonnes per hectare during 1981 to 1985 to 1.5 tonnes per hectare during 1996 to 1998. (See Table 6.2 below).

Table 6.2 Average Production of Maize in Ghana

	1981-1985	1986-1990	1991-1995	1996-1998
Average Production ('000 tonnes)	373	635.16	919.32	1014
Average area cultivated ('000 ha.)	454.8	491.48	630.38	675
Average production per area (tonnes per ha.)	0.82	1.29	1.49	1.50

Source: Calculated using data from MOFA (1999)

It is difficult to establish the extent to which the success in achieving an improved yield of 1.5 for the period 1996 to 1998, from a low of 0.82 for the period 1981 to 1985 is attributable to the application of biotechnology. As indicated, the increase in yields came during the period of the GLDP when efforts were made to develop specific genetic traits in the grains. But other factors such as improved weather conditions and other socio-economic programmes such as the Economic Recovery Programme were also implemented during the period. Even if only indirectly, these programmes might have created incentives for farmers to improve on efficiency and this reflected in higher yields. Still, given the fact that the achievable yield for maize is 5.0 tonnes per hectare, the present average production yield of 1.5 tonnes per hectare is only about a third of the achievable (MOFA, 1999, p.9).

In a diagnostic study of research and development of technology in Ghana, one of the conclusions made was that, a number of researches had been done in the past but had not significantly translated into productivity (Aryeetey, 2000, p.49). The challenge therefore for biotechnology is that, with the more advanced tools and techniques there should be significant contributions towards enhancing production or productivity in terms of achieving higher yields. This however depends on creating a dynamic intercourse between the supply and demand sides of technology generation and ensuring a holistic capacity development – that is, the capacity to generate innovations and the capacity to absorb innovations.

6.7 The Quality Protein Maize

Another project that highlights lessons in developing capacity from the demand side is the Quality Protein Maize Project, which led to the development of Obatampa maize. In the case of Obatampa maize, it achieved significant success on the demand side for a couple of reasons. At the end of the research and development activities, it was proven to be nutritionally superior maize to other varieties. This was demonstrated in a study involving children and infants of farmers growing the Obatampa and another variety (Twumasi-

Afriyie *et al*, 1999, p.22). It attracted industrial interest with well-known industrial establishments adopting it for some of their products. For example, from Obatampa Nestle Ghana Ltd produced infant formulas and maize grits, Agrimat produced dried fermented flour and Guiness Brewery produced malt (Twumasi-Afriyie *et al*, 1999). In 1992 Obatampa constituted only 17% of the quantity of certified seed produced in Ghana. However in 1997, it constituted 77% of the improved seeds certified for sale to farmers and it is estimated that currently, at least 130,000 hectares (20% of Ghana's maize area) was planted to Obatampa, with an expansion rate of about 50% (Twumasi-Afriyie *et al*, 1999).

The important lesson the adoption of the improved maize highlights is that, where conscious efforts are made to extend technologies a high degree of success is achieved. In the case of Obatampa, the political authorities participated in the extension process with Ghana's President J.J. Rawlings not only showing interest in Obatampa but also giving recommendation to farmers and encouraging them to adopt it. The former U.S. President Jimmy Carter was also involved in its extension. There was strategic marketing and distribution through the seed growers leading to the significant adoption by the farmers, food processors and poultry feed producers.

Indeed the process of addressing the demand side equation of capacity building involves a multiplicity of strategies, which may even trace back to the inception of the Research and Development phase. The interactions with the end-users such as the farmers, food processors, and poultry feed producers and established industries contribute to the level of success attainable.

6.8 Improvement of Crop Varieties

The goal to improve planting materials underlines the R&D activities in a number of tertiary and research institutions including the Crops Research Institute, the Cocoa Research Institute, the Oil Palm Research Institute and the Crops Science Departments of the universities at Kumasi, Cape Coast and Legon. The development of new or improved crop varieties had involved a number of techniques across the spectrum of biotechnology. At the rudimentary level, there had been grafting or vegetative propagation to produce early maturing planting seedlings such as for citrus, mangoes and other fruit trees. This was a traditional technique that hardly needed any in-depth scientific knowledge. In this type of vegetative propagation a stem of the desirable plant variety was cut, joined to a stock and nurtured to grow. Any farmhand under the supervision of the technical assistant could do the cutting and the joining. Therefore the knowledge intensity for this activity was low.

The more specialised crop improvement involved the cross-pollination of identifiable varieties of the crops. The aim was to develop crops that genetically possessed the desired traits observed in the parent varieties. The initial step involved the selection of the preferred plants in subsequent filial generations based on phenotypes. Cross-pollination techniques had been used in the production of a number of crop varieties and extended to farmers as presented in table 6.3 below. Over the years, about 25 million oil palm seedlings or germinated nuts of improved varieties have been sold out for planting (OPRI, 1999).

A further advancement of crop improvement was the application of mutation techniques to induce changes in the genetic constitution of the crops. In Ghana, the establishment of BNARI at the GAEC facilitated the usage of gamma-irradiation to improve crops. BNARI has had collaboration with CRIG in the development of cocoa resistant strains against the CSSV. One of the earliest attempts in Ghana to modify and thereby improve the genetic constitution of a crop was the attempt at mutation breeding at the Cocoa Research Institute of Ghana (CRIG). In the strict sense of "genetic engineering", mutation breeding is only a conventional technique that brings about genetic modification in a random and unpredictable manner. It does not compare with the actual technique of genetic engineering, which involves the identification and isolation of a specific gene of an identified trait and the insertion of the same in a particular crop with the view of imparting the identified trait to the crop. Genetic engineering is a predictable and targeted technique, which is the acme of plant biotechnology (Jones, 1990).

Table 6.3 Improved Crop Varieties Available to Farmers

Crop	Improved Varieties	Desirable Traits
Maize	Aburotia, Golden Crystal, Dobidi, Obatampa, Dadaba, Mamaba.	Early maturity between 90-120 days, resistance to streak virus, enhanced protein content
Cowpeas	Boafo CRI, Soronko, Asontem, Bengpla.	High yields, higher tolerance of pests and diseases
Cassava	Afisiafi, Glemo Duade and Abasafita	3x yield of local varieties, resistance to pests and diseases.
Sorghum	Naga White, Kadaga NSV-1, NSV-2, Kapaala, *Framida.	High yields, *high quality beer brewing trait.
Groundnut	F-mix and Sinkaza	High yields

Source: Derived from various annual reports of institutions of the NARS

The development of new improved varieties has currently advanced to involve the use of modern techniques such as molecular markers and genetic bombardment. At the Cocoa Research Institute of Ghana, scientists are able to screen for specific traits such as resistance to Cocoa Swollen Shoot Disease (CSSD) and the blackpod diseases.

Whilst one is looking at the supply side of improved planting materials, one also has to look at how it is faring on the demand side. Morris *et al* (1999) have shown that there has been extensive adoption of generated maize technologies. During 1997, 54% of their sample farmers planted improved varieties of maize on at least one of the farms belonging to the farmers. Based on the farmers' own qualitative judgement, the adoption of the improved varieties has been associated with significant farm-level productivity gains and noticeable in the income earned from sales of maize (Morris *et al*, 1999, p.37). But in the fieldwork for this thesis, it is clearly that in the New Juaben district, the average income of farmers sampled is only about $75 dollars per year which is below a one-dollar daily wage.

6.9 Technological Capability in Molecular Biology

Some institutions have developed capability in molecular biology and are applying it in their R&D activities. The Oil Palm Research Institute (OPRI) is faced with the challenge to address the mandate of selection and breeding for desired characteristics such as high yields, disease tolerance and shortness in oil palm and coconut and to address the epidemiology and control of prevalent diseases. These are improved planting materials developed through the conventional techniques of cross-pollination.

However, for coconut research and development, OPRI set up the coconut project with modern biotechnology capacity. In this connection, the polymerase chain reaction (PCR) assay technique is routinely used as a diagnostic tool for the detection of coconut phytoplasma in the cococut plant and suspected insect vectors. This is an important tool for identifying, detecting and confirming the presence of phytoplasma, the causal agent of the Cape Saint Paul Wilt Disease (CSPWD), the lethal yellow type disease, and enable the determination of the vectors and alternate hosts of the pathogen. Such tools are also needed for epidemiological monitoring. It is even doubtful whether without these tools, so much progress would have been made in the study of the disease given the long life-cycle of coconut and the unknown nature of the disease. Again, specific projects supported with donor resources are what have made it possible for the capacity development. Under the Coconut Lethal Yellowing Project, the Overseas Development Agency (ODA, now known as the Department for International Development or DFID) of the U.K. established a molecular biology laboratory at the Crop Science Department at the University of Ghana (Personal Communication, 2000).

The future directions of R&D at the OPRI being contemplated is the study of the physiological and genetic behaviour of some progenies of oil palm under drought conditions for selection of drought adapted lines for increased production. Molecular biology applications would involve DNA finger-printing of the drought-resistant traits in the adapted oil palm lines to facilitate selection.

At the Forestry Research Institute researchers have screened populations of Odum to identify lines that are resistant to the destructive insect pest known as *Phytolyma lata*. DNA finger-printing has been used to determine the gene profiles of the resistant and susceptible lines. The researchers also worked on producing true-to-type planting materials from trees of desirable traits such as good form (Personal Communication, 2000).

At the Crops Research Institute (CRI) there are the uses of Enzyme-Linked Immuno-Absorbent (ELIZA) techniques to screen for diseases in various crops such as cereals, legumes and vegetables. The use of isoenzymes in screening at the CRI is however incomplete. To make the screening more effective, there is need to resort to the use of DNA markers (Personal Communication, 2000).

The trend that emerges in analysing the state of molecular biology is that there are capabilities in most of the R&D institutions that can be harnessed to address specific national needs. A critical core of human resources is available and this can form the springboard for others. The major constraints have been the inadequacy of the physical facilities either due to defective equipment or lack of needed equipment and insufficient funding. The trend has been that donor funding has provided the base for the initiation of projects that invariably create capacity in terms of provision of equipment, training of manpower and sometimes the development of the infrastructure. However, donor funding tied to projects is intrinsically not sustainable. The issue of sustainable funding for biotechnology capacity building therefore remains at the centre stage of the discussion.

6.10 Policy Instruments - Commercialisation of Biotechnology Innovations

The need for commercialisation of the technology highlights the necessity for bridging the supply and demand sides of biotechnology innovation. A cornerstone of this thesis has been that capacity building should embrace both the supply and demand ends of innovation. The question of interest is whether there are innovations to commercialise. The innovations are simply the outputs produced with the application of some biotechnology techniques such as improved planting materials and biofertilisers. The biotechnology techniques themselves such as tissue culture offer prospects for commercial activities.

In other African countries such as Kenya and Zimbabwe, not to mention South Africa, commercial tissue culture enterprises are in operation. In fact, tissue culture work in

Kenya dates back to 1979 when the Pyrethrum Production Board contracted the Kenya Agricultural Research Institute (KARI) to develop the technology for the Board's pyrethrum programme (Alhassan, 1999). Now there are tissue culture enterprises such as Genetic Technology Ltd. (GTL), Oserian Company and Sulmac Company producing planting materials for farmers on commercial basis. The plants tissue-cultured are pineapples, sugar cane, macadamia, cassava, pyrethrum and cut flowers (Alhassan, 1999). The investment level needed for commercialising tissue culture is substantial but perhaps not beyond most investors in Ghana. A fairly standard tissue culture laboratory attracts the level of costing detailed in Table 6.4 below (with further details in the Appendix 3):

Table 6.4 Summarised Cost of Standard Tissue Culture Laboratory

Equipment and Facilities	Cost in Cedis ('000)	*Cost in US dollars
Key lab equipment and supplies	309,440.00	44,205.71
Other equipment and supplies	76,000.00	10,857.14
Farm facilities	34,000.00	4,857.14
Total	419,440.00	59,919.99

Source: Based on information obtained from key informant.

Note: * The exchange rate is 7,000 cedis to one US dollar (2001)

The total cost estimate for establishing a tissue culture laboratory is in excess of 400 million cedis or roughly US$60,000 (Personal Communication, 2000). It is a conservative estimate given the fact that consumables such as pre-filter hoods and surgical blades would need further budgeting for. Items such as reagents and stationery have also not been catered for. More importantly, the infrastructure, specifically the building and related structures, are assumed to be in place. Nevertheless, the estimate is within the financing capacity of local investors including the banks. Why such an investment would not be made relates to a number of factors. For example there is the unpredictable nature of the venture and therefore the difficulty in forecasting returns on financial investment as well as the poor perception on the part of the private sector that research and technology development is a public good (Aryeetey, 2000, p.5). However, investment is an important component of the mechanisms in capacity building. In the case of biotechnology, the bulk of the advancement and application of the technology worldwide is private sector driven (Cooper, 1994; Fransman 1995; Avramovic, 1996). If Ghana should make serious strides in biotechnology capacity building, then the investment potential available within must be harnessed and certain misgivings about technology development have to be corrected. The point reflects the propositions made in the conceptual framework that the endogenous factors have effect on the biotechnology capacity. Investment policies, the science and technology culture and the local market situation constitute variables that can be positively activated to create the needed capacity. Besides, the private sector is an important change agent, which facilitates the capacity building process.

The onus is also on the scientists or researchers in the innovation system to adopt a proactive stance regarding private sector participation in their activities. There should be greater propensity to demonstrate market proven technologies. It re-echoes the point that the supply and demand of generated innovations should find a dynamic intercourse.

There are indications though that the potential for demand support for commercial tissue culture is manifesting with exporters of non-traditional crops, especially pineapples exporters, making contacts with the R&D institutions for multiplication of specific varieties of the crops. For example the Greenspan Farms commissioned BNARI to multiply up to 10,000 plantlets, two new cultivars of pineapples - H132-1650T and H132-2709T. Milani Farms also approached BNARI to produce two other pineapple cultivars, Queen1 and Queen7 (Personal Communication, 2000). There are other commercial farmers in Ghana desiring such tissue culturing services.

However, it is important to distinguish between real or actual demand and potential demand that can be envisaged on the basis of mere indications of interests. For example, the government even goes beyond mere expression of interest to place orders for tissue cultured planting materials for distribution to farmers. But the actual commercial demand is that which farmers' willingness and ability to pay the negotiated cost of the biotechnology products support. This is different from the demand that comes virtually under government fiat. For example, MOFA has requested BNARI and the Botany Department of the University of Ghana on a number of occasions to multiply crops for distribution to farmers and most of these requests were not backed with financial commitment. For example, BNARI has a MOFA order to multiply nine cultivars of sweet potato for farmers. By the end of 2001, BNARI was required to deliver 5,000 of the plantlets (Personal Communication, 2000). Government orders are desirable if they come at commercial rates and payments for them are made and in good time. Unfortunately, quite often they are not. As it were, the real demand is that of commercial farmers who even sometimes negotiate the cost of the tissue culturing services downwards with the arguments that already their overheads prior to export of the crops are already high. The government can however decide that as a matter of priority, it is providing budgetary assistance to the application of tissue culturing in support of the promotion of non-traditional crops. Besides, all government's orders should come at commercial rates with full payments. In so doing, the government will be making the commercialisation of tissue culture profitable and the private sector can take interest in it.

6.11 Biotechnological Projection for the Future

The global trend in the development of biotechnology has shown a number of characteristics. There is an increasing application of all techniques along the lines of the gradient of biotechnology development. In particular, the application of genetic engineering in crop agriculture as is other sectors of the economy is becoming the norm rather than the exception.

Even in Ghana, there is a tendency towards an increased application of biotechnology. For example tissue culture, molecular biology techniques are becoming routine applications in R&D. If these are any indications of what to expect in the future, then Ghana is also likely to move up the gradient of biotechnology development especially with the application of genetic engineering. That scenario however raises issues concerning the gaps in the biotechnology capacity in the organoware, inforware, humanware and technoware. The next chapter addresses this.

CHAPTER 7

EXPERIENCE AND BEST PRACTICE FROM SELECTED COUNTRIES

7.1 Introduction

This chapter does a comparative analysis of the experiences of other countries in biotechnology application, development and management. It aims at addressing the question of what lessons are there in the experiences of other developing countries in biotechnology capacity building. The countries have been purposively selected because they are predominantly developing countries and have carried out biotechnology capacity building in their own national contexts. The countries include South Africa, Kenya, Mexico, Malaysia, India and Korea. Three advanced countries namely the U.S., Germany and Japan have also been included here to highlight developments at the frontiers of biotechnology. The chapter establishes the common elements of best practice and on that basis identifies and analyses the gaps in biotechnology capacity building in Ghana.

7.2 The Diversity of the Developing Country Contexts

From the outset, the point needs to be emphasised that the term "developing country" is a misnomer in the sense of grouping countries of similar socio-economic backgrounds together. The diversity in the socio-economic contexts of the countries sometimes makes it unrealistic for the term to be applied. Table 7.1 illustrates the point.

Table 7.1 Selected Indicators of Some Developing Countries

Indicator	Mexico	Malaysia	Brazil	India	Ghana	Kenya
Human Development Rank	51	56	69	115	119	123
Population (1999 million)	97.4	21.8	168.2	992.7	18.9	30.0
GDP per capita (ppp US $)	8,297	8,209	7,037	2,248	1,881	1,022
Population below National Poverty line (1984-99) %	10.1	15.5	22.0	35.0	31.4	42.0
R&D Expenditure as % of GNP (1987-97)	1.3	1.2	0.8	0.7	-	-
Scientists and engineers in R&D per 100,000	214	93	168	149	-	-
Fertiliser consumption – kg per hectare of arable land cropped (1998)	62.5	184.9	88.0	99.1	2.9	28.2
Tractor in use per hectare of arable land cropped ('98)	6.3	5.7	12.4	9.1	0.7	3.2

Source: UNDP (2001) Human Development Report 2001, UNDP, New York.

For example, the GDP per capita of Mexico in purchasing power parity is about eight times that of Kenya. The difference reflects in the wide gap in their human development ranking with Mexico being at 51 and Kenya being at 123. The economic differences also translate into the S&T systems in the respective countries. Using fertiliser consumption as an indicator of S&T application, Mexico uses 62.5 kg per hectare of farmland as against 28.2 for Kenya. Comparing Malaysia's fertiliser consumption of 184.9 kilograms per hectare farmland to that of Ghana's 2.9 makes the difference more remarkable. Thus there is great diversity among developing countries such that, putting them together as a collective does not make for effective analysis.

Nevertheless, relative to the socio-economic contexts of the advanced countries, it does make some sense to group developing countries together. The socio-economic differences between the two worlds – i.e. the developed world and the developing world – more or less justify the generalisation. Besides, the sub-divisions of the developing countries such as the least developed countries (LDCs) and newly developed economies are making the grouping more realistic in terms of the socio-economic contexts. This thesis therefore proceeds with the comparative analysis of the country experiences on the basis that, there are identifiable elements in their approaches to biotechnology capacity building that have relevance for Ghana.

7.3 Malaysia

The Malaysian government identified biotechnology as one of the five key enabling technologies in the Seventh Malaysia Plan (1996) for priority action (Tzotzos and Skryabin, 2000). The Plan emphasised that the "greater use of technology and the development of a strong domestic capability are major factors in meeting the objectives of productivity-driven growth and industrial competitiveness" (ibid). In this regard, the government established the National Biotechnology Directorate (NBD) in April 1995 with functions including:

- assessing national and global development in biotechnology with the view to identifying opportunities that could be harnessed by Malaysian industry,
- identifying focal points for specific areas of biotechnology,
- enhancing national capabilities through training of scientists, technologists and other related personnel,
- providing common facilities for scale-up and prototyping where necessary,
- promoting biotechnology within the business sector with the aim of commercialising R&D outputs and creating spin-off commercial activities.

Although it cannot be established how much was specifically voted for carrying out these functions, the government demonstrated substantial commitment. But it is known that the national commitment to R&D generally is about 1.5 of GDP. It established the Intensified Research in Priority Areas (IRPA), which aimed at the following:

- The development of indigenous research capacity for industrial development, especially in new and emerging technologies.
- Guidance of the overall direction of research programmes of public sector research institutions.
- The creation of linkages with postgraduate education in areas of national need.
- The promotion of closer linkages between public sector research and industrial organisations (Tzotzos and Skryabin, 2000).

The R&D allocation for the implementation of the Seventh Malaysia Plan through the IRPA came to $480 million which was only a little short of the government's own target. An analysis of the IRPA-funded R&D under the Sixth Malaysia Plan revealed that the agricultural sector received the largest percentage of 46.55% of funds and the strategic sector comprising the emerging technologies received 13.36% with two-thirds of this going to biotechnology (Tzotzos and Skryabin, 2000). Many of the research institutions and universities that received IRPA funding are involved in biotechnology activities. In four of the five S&T sectors a total of $20 million for 67 projects was provided in the Sixth Malaysia Plan. This implies an average of about $304,000 per project (Tzotzos and Skryabin, 2000). Thus resource allocation for biotechnology development and S&T development generally is an important factor in Malaysia's scientific advancement.

The government also initiated policies to regulate biotechnology applications. In 1996, the Genetic Modification Advisory Committee (GMAC) was endorsed with the mandate to handle all issues pertaining to genetically modified organisms (GMOs) including their use and safe transfer. The Committee has oversight of risk assessment and risk management and is responsible for co-ordinating the relevant enforcement agencies and other institutional biosafety organs (Tzotzos and Skryabin, 2000).

Malaysia is one of the twelve mega-diversity countries in the world harbouring a vast range of flora and fauna. 58% of its landmass is still covered with natural forests. It has put in place a well-defined regulatory framework for the protection of its biodiversity and has acceded to the Convention on Biological Diversity. It has also drawn up its own National Policy on Biological Diversity. It goes to underscore the fact that the government is directing the use of biotechnology to the exploitation of its natural endowment.

For example in Malaysia the focus is improving cash crops and biotechnology is applied to building a reliable export-driven oil palm industry. The two most important sources of vegetable oils and fats on the world market are soya and oil palm. The productivity of oil palm in terms of oil yield per tree is increased 30% by cloning high yielding oil palm trees (Cooper, 1994). Malaysia's oil palm industry was so successful that large plantations of rubber were converted to oil palm plantation. The success of Malaysia with oil palm is one of the striking examples of what biotechnology can do when applied strategically.

7.4 Korea

The development of biotechnology in Korea drew on the long tradition of fermentation. The development began systematically in the 1980s when the government established the Korea Genetic Engineering Research Association in March 1982, which was a consortium of 13 companies with interests in biotechnology. Biotechnology was one of the seven strategic areas of national development in 1982 and the Korean Research Council for Applied Genetics was set up to promote and coordinate research activities in the universities. The Genetic Engineering Promotion Law was also passed in 1984 (Tzotzos and Skryabin, 2000).

Biotechnology R&D has progressed substantially increasing more than 40% annually. National R&D expenditure reached $9399 million in 1994 corresponding to 2.45% of GNP. More importantly, of this colossal amount, the government contributed $1515 million and the rest came from private investment (Tzotzos and Skryabin, 2000). Among the institutions these public and private investments support are:

- Korean Research Institute of Biosciences and Biotechnology
- Korean Biotechnology Research Association (with 21 member companies)
- Department of Bioresources, Rural Development Agency
- Life Science Division, Korea Institute of Industry and Technology Information.

Korea is looking forward to an expanded biotechnology market. Its market has expanded from $25 million in 1989 to $ $200 million in 1993. It was expected to have reached $4 billion by the year 2000 and reach $17.5 billion by 2005. Domestic production was 56% of the total market in 1993 and it was expected to cover 62% by 2000 (Tzotzos and Skryabin, 2000).

Clearly, Korea is a country where government has demonstrated foresight and initiative in the development of biotechnology dating back to the 1980s. It has shown how crucial investment in biotechnology is and the extent to which the private sector could respond to government initiatives when effectively packaged. The quantum of financial commitment to science generally, which is 2.5% of GNP illustrates the high priority Korea places on S&T. What is emerging from the Korean experience is also that public investment is an important element in best practice.

7.5 India

The government established the Department of Biotechnology (DBT) in February 1986. The establishment was a sequel to the National Biotechnology Board, which the Scientific Advisor to Cabinet set up to foster programmes strengthening indigenous capabilities. It created a viable infrastructure for biotechnology research and services in national laboratories and academic institutions (Tzotzos and Skryabin, 2000).

A regulatory framework was also established with the formulation of the Recombinant DNA Guidelines in 1990 and revised in 1994. Following the publication of the guidelines, contained use of GMOs began in 1993 with the first field trials occurring. Apart from this, there have been successful programmes in biological pest controls, biofertilizers, aquaculture, embryo transfer technology and plant tissue culture. These has resulted in the following:

- 55,000 hectares of land under biological pest control
- development of new biofertilizer technology packages
- standardisation of embryo transfer technology
- setting up of tissue culture plants
- setting up of a bioinformatics system through ten Distributed Information Centres and 23 sub-centres all over the country.

Besides, the DBT has established seven centres of plant molecular biology in universities and national laboratories with two network projects for the development of transgenic cotton and the improvement of quality in wheat. Already there are successes with transgenic rice and cotton containing insecticidal genes (Tzotzos and Skryabin, 2000).

There have also been successes in other areas. For example the tissue-cultured institutes have effectively applied the micropropagation technology to conservation and the protection of the environment. Three million tissue-cultured plantlets of elite forest trees have been planted over an area of 2,500 hectares. R&D efforts have led to the development of twenty protocols for a number of horticultural, plantation crops and forest trees. Tissue culture is used on a commercial scale with an established demand for disease-free cardamon, cut flowers, exotic ornamental plants, vegetable seeds, sunflower and tomatoes (Tzotzos and Skryabin, 2000). The DBT has established main research laboratories and institutions namely:

- The National Institute of Immunology, New Delhi,
- The National Centre for Cell Science, Pune,
- The Centre for DNA Fingerprinting and Diagnostics at the Centre

for Cellular and Molecular Biology, Hyderabad (Tzotzos and Skryabin, 2000).

India also supported the development of the International Centre for Genetic Engineering and Biotechnology (ICGEB) with a component operating in New Delhi focusing on agriculture and human health care. For India, biotechnology has already made impact in many important sectors particularly in the area of environmentally sustainable development. It has encouraged the development of new initiatives including the following:

- bioprospecting of biological resources
- establishment of a Micropropagation Technology Park
- transgenic animals and plants
- edible vaccines
- establishment of a Centre for Bioresource Development (Tzotzos and Skryabin, 2000).

7.6 Brazil

Brazil's attempts to institutionalise a public policy specifically for biotechnology climaxed in the establishment of the Special Biotechnology Secretariat (SBIO) attached to the Ministry of Science and Technology (MCT). The Secretariat was created to define and co-ordinate national policy for biotechnology developments in Brazil. The attempts could be traced to the National Alcohol Programme (PNA) initiated in 1975. In 1984, a National Biotechnology Programme was set up and consequently implemented with World Bank resources under the auspices of the Programme for Supporting Science and Technology Development. The biotechnology programme placed high priority on the development of indigenous capabilities in research, development and industrial applications in agriculture, energy and health (Galhardi, 1994). The specific objectives were:

- increasing the number and quality of human resources by training, abroad or at home, the existing critical mass of scientists in biotechnology-related areas in general and in genetic engineering in particular; and
- implementing the national network of reference cell collections. An average of US $10.4 million per annum was invested in biotechnology developments from 1985 to 1989 through the integrated effort of four government agencies focusing on:
- building-up human resources,
- guaranteeing essential services, such as scientific and technological information, maintenance of equipment, and research inputs,
- promoting transfer of technology among research groups within the country and abroad, and between the national research groups and the production sector, and developing R&D activities (Galhardi, 1994).

In assessing the Brazilian efforts at implementing a public policy for biotechnology, Galhardi (1994) concluded that there was a failure to prioritise the biotechnology initiatives as biotechnology was defined across the range of the biotechnology spectrum. It included the most recent discoveries of genetic engineering as well as the older microbial processes such as fermentation. Under the biotechnology programme, most of the activities were carried out in the universities and research institutions with very little integration among themselves or between them and the commercial sector. Thus the "political and economic fragility of Government and lack of coordination and integration among institutions, left the Braziiian biotechnology policy without any sense of direction" (Galhardi, 1994).

The point cannot be over-emphasised that the lack of co-ordination and harmonisation of institutional objectives is a recipe for failure. Not surprisingly, the Rio de Janeiro Science-Industry Park for Biotechnology built in 1989 to promote interaction between scientific institutions and industrial enterprises, has only attracted a few small firms. Its role as a promoter of industrial biotechnology is yet to be proved. All this shows that, despite the lack of an explicit S&T policy for biotechnology, the Government has been trying to set up mechanisms to stimulate scientific and technological development in biotechnology-related areas. Galhardi (1994) concludes that the success of the policy initiatives depends not only on an explicit policy, "but also, or maybe principally, on implicit policies such as those embodied in general economic, industrial and trade policies, and their mechanisms of implementation which may help to avoid the perpetuation of the status quo."

Brazil's experience in the importation and diffusion of transgenic crops through TNC investment also holds important lessons for other developing countries. The case of the battle between Monsanto, a TNC on one hand, and various interest groups and farmers' associations for the approval of genetically modified soyabean shows the intricacies in operating legislative and regulatory mechanisms in respect of transgenic crops (Palaez and Schmidt, 2001). The TNC was set on obtaining approval for its transgenic soyabean and was ready to use all possible means. Monsanto even invested in part acquisition of the main Brazilian Agricultural Research Enterprise (EMBRAPA), which is the largest state agricultural R&D organisation in the country in the hope of using its capabilities to promote its business interests. Brazil is the world's seventh largest exporter of agricultural products and the second-largest exporter of soya (Palaez and Schmidt, 2001). However, Brazil's soya exports are not transgenic and therefore seem to have a competitive advantage on the European markets where controversies over transgenic food products have created difficulties for American exporters whose soya exports are about 70% transgenic (Palaez and Schmidt, 2001). It is critical for Monsanto's business interests to diffuse the genetically modified soya crops in Brazil to erase the competition. The various interests groups – farmers and NGOs – had to go to the Supreme Court to enforce the regulatory and screening procedures for the approval of the transgenic crops (Palaez and Schmidt, 2001). The dynamics in this particular case underscores the need for proper mechanisms for legislation and regulation in biotechnology application and development. It also underscores the need to manage the process to ensure that the interests of the critical stakeholders are protected equally and fairly. In all this, the national interest should be paramount.

7.7 Mexico

In Mexico, research in plant biotechnology began as far back as 1969 when an agreement for scientific collaboration was signed between Mexico and Japan leading to the building of the first tissue culture laboratory at the Postgraduate College of Chapingo. The Japanese company Matsumoto with interest in ornamental plants established the second laboratory in 1972 (Casas, 1999). The development of capacity in biotechnology extended into other areas including the production of biological fertilizers as alternatives to chemical fertilizers and the modernisation of the fermentation industries which has thrived as a traditional biotechnology in pre-

Columbian times. The use of industrial waste to produce single-cell proteins (SCP) using micro-organisms was also developed. Despite the efforts in building capacity in biotechnology as a national agenda, the emphasis has mainly been on the supply side without adequately giving corresponding attention to the demand side. As Casas (1993) stated, "Mexico is demanding attention from the campesino (traditional) sector, and the development of agricultural technologies should consider the problems related to that social sector." This is a problem of the agriculture structure of Mexico which had not had "the benefit of and extension service" such as exists in the U.S. with the Department of Agriculture linking with land grant colleges and thereby creating "an integral link between university researchers and producers" (Wagner, 1998, p.70). It appears however that there is an emerging generation of producers who are "forcing a change by weaving new technology into traditional agriculture." Mexican researchers and business people are becoming increasingly aware that the economic strides fostered by technological innovation require not only a scientific base, but also its transfer to the marketplace. Wagner (1998) states that the greatest challenge facing the country is strengthening the infrastructure that catalyses the linkage between the scientific base and the marketplace.

In Mexico, the National Council for Science and Technology (CONACYT) has estimated that 1 to 5 percent of the 22,600 scientists in Mexico work in industry (Wagner, 1998). Biotechnology in Mexico also mirrors this general pattern. The various scientific disciplines related to molecular biology and genetics, as well as the bioengineering related to production scale-up, are concentrated in a handful of academic or governmental research centres and international organisations. R&D in these centres involves the generation of new knowledge, techniques, and processes (Wagner, 1998).

A number of new agro-biotechnology applications have been made in Mexico. For example, the multinational Calgene has introduced genetically modified cotton for planting. Biogenetica Mexicana employs micropropagation techniques in the production of flowers for domestic sale and export. Another Mexican company in the Yucatan micropropagates flowers as well as blue agave, which as the basis for tequila production, is attracting interest on the global market. Laboratorios Colombia produces a yeast-based antibiotic based on a patented technology developed at the Centre for Research and Advanced Studies (CINVESTAV). CINVESTAV has also developed and implemented field trials of transgenic asparagus and, in conjunction with Monsanto, is testing locally adapted transgenic potatoes (Wagner, 1998).

Mexico views biotechnology as a tool for achieving the twin objectives of providing appropriate technology to smaller rain-fed farmers and increasing the productivity of the export sector. Mexican biotechnology research is concentrated solely on developing applications of plant biotechnology. Plant tissue culture techniques were introduced in the 1970s. Currently, these techniques are the key tools for basic research and the production and indexation of virus-free seed-potato (papa) stock is mainly concentrated at the National Agricultural Research Institute for Potatoes (INIFAP) in Toluca which is linked to the International Potato Centre (CIP) in Peru. Research at the Universidad Autonomia de Chapingo (UNAC) has attempted to establish continuous sanitation program of cultivars resistant to Late Blight through thermo-therapy techniques and in vitro tissue culture techniques to obtain virus-free plants of the most promising blight-resistant clones (Marks *et al*, 1992, p.19). If rain-fed farmers do not adopt the technology, the productivity gap, which already exists between themselves and large-scale, mechanised or commercial farmers could widen. One way to induce adoption of the technology would be through a policy of input subsidies and or increased supplies of credit (Marks *et al*, 1992).

7.8 Cuba

Cuba is one developing country that has successfully created a biotechnology capacity. A UNIDO team of experts in 1986 undertook a survey of developing countries to assess capacity of the various countries for setting up the International Centre for Genetic Engineering and Biotechnology (ICGEB). The team judged Cuba to have one of the best biotechnology programmes in the Third World. In Cooper's (1994) discussion of Cuba's success, certain key factors that stand out were:

- the emphasis given to the role of science in Cuba
- the development of a core scientific capability
- creation of a centre of excellence.
- the identification of a critical "entry point" in biotechnology production of interferon (Cooper, 1994).

The Cuban Academy of Sciences was originally established in 1861. After the Cuban revolution in 1959, it was restructured substantially. With 77 distinguished scientists elected from all sectors of Cuba's society, the Academy employs about 10% of the total number of scientists and engineers directly. The Ministry of Higher Education is also an important stakeholder in biotechnology development as it established the National Centre for Scientific Research (CENIC) in 1965. As a major biomedical and chemical research centre, it has a staff of about 1,000 with four main divisions including biomedicine and bioengineering. One of the important spin-off institutes of CENIC is the Centre for Biological Research (CIB). A "Biological Front" emerging in 1981 consisting of scientists and policy-makers, co-ordinated and articulated the interests of the institutes and organisation involved in biotechnology in Cuba. It became a high-level policy making body relatively autonomous from the Academy and the various ministries. The Biological Front supervised the establishment of the CIB and later the Centre for Genetic Engineering and Biotechnology (CIGB) (Cooper, 1994).

CIB beginning with a staff of six went into production of interferon for use as an anti-viral agent in the outbreak of dengue fever, which attacked about 300,000 people and killed 158 (Cooper, 1994). The health service was a priority area of Cuba and therefore the production of interferon addressed the specific national health need. However, CIB used the production of interferon as a 'model' for the development of the wider range of capabilities and assets. Interferon was used to develop a biotechnology-creating system with expertise in the areas of genetic engineering and bioprocessing. It has developed into a centre of excellence and has extended its capacity to the production of restriction enzymes, the synthesis of oligonucleotides, cloning and expression of various genes and the production of monoclonal antibodies for diagnostic purposes. Naturally, though the gradual build-up of modern biotechnology capacity in Cuba started in the health sector, it extended to various sectors of the economy including agriculture. Apart from the benefits from the capacity to work with generic systems in genetic engineering and bioprocessing, a special group was established at the CIGB for plant breeding and engineering. This group does research on improved plant varieties and other areas such as nitrogen fixation. In this way, the capacity development that intensified in the health sector extended to agriculture.

Cuba's public investment in S&T development is substantial. Government expenditure in R&D has been roughly 1% of GDP in the early 1990s increasing to about 1.4% in 1994 (Tzotzos and Skryabin, 2001). This expenditure covered infrastructure support, current operation expenses and salaries. However there are other sources of funding such as from product commercialisation, scientific services, and international collaboration among others.

The legislative and regulatory framework for biotechnology development is also well spelt-out in Cuba. The National Centre for Biological Safety regulates activities in connection with biosafety, genetic manipulation, and containment of GMOs, release of transgenic organisms and the biodiversity. The Cuban Office of Intellectual Property administers patents under the Decree-Law No. 68 on Inventions, Scientific Discoveries, Industrial Models, Trademarks and Denominations of Origin of 1983 (ibid). Subsequent amendments to this law enable patenting of modified living organisms. The legislative and regulatory system for biotechnology applications is fairly well addressed.

Indeed Fransman (1991) notes that the experience of Cuba illustrates the dramatic achievement that can be made with a firm commitment to the development of biotechnology capabilities and their application to a wide range of areas in accordance with the country's economic priorities.

7.9 Kenya

Kenya's capacity for biotechnology development is more advanced compared to Ghana. Six research institutes were set up under the Science and Technology Act of 1979. The Kenya Agricultural Research Institute (KARI) is the most important public research institution engaged in biotechnology in the country (Alhassan, 1999). There are five research centres in KARI engaged in biotechnology research namely:

- National Pyrethrum Research Centre, Molo
- National Potato Research Centre, Tigoni
- National Horticultural Research Centre, Thika
- National Research Laboratories, Kabete
- National Veterinary Research Centre, Muguga.

Some biotechnology has actually entered commercialisation. For example, a number of tissue culture companies are operating in Kenya. Genetic Technology Ltd produces tissue culture planting materials of pineapples, sugar cane, macadamia, cassava and pyrethrum for farmers. The Oserian Company also mass-produces flowers for the export market. One of the interesting private sector-sponsored initiatives is the attempt to develop a transgenic sweet potato variety that is resistant to the feathery mottle virus. It is a KARI-Monsanto initiative supported by USAID operating within a special license agreement between KARI and Monsanto aimed at transferring technology to the KARI scientists. Human resource is one of Kenya's main strengths. As of 1996, there were a total of 41 biotechnology researchers of Ph.D. level, 15 of M.Sc. level and 9 of B.Sc. level in Kenya (Wafula and Falconi, 1998).

Indeed, Kenya has a well-structured institutional arrangement for agricultural biotechnology research and development. There is a strong manpower base and a positive private sector involvement in agricultural biotechnology. More importantly, there is a trend towards more advanced biotechnology research and development. However there are the weaknesses of dominant donor funding which is not sustainable and the development of a biosafety regime has been slow though structures have been put in place for regulation (Alhassan, 1999).

The National Council for Science and Technology (NCST) is the national focal point for biosafety and is a member of the African Regional Focal Point for Biosafety based in Harare. The various laws that pertain to biosafety are the Seed and Plant Varieties Act, the Plant Protection Act, the Crop Production and Livestock Act and the Food, Drugs and Chemical Substances Act. With regard to intellectual property, there is the Kenya Industrial Property Office established under the Industrial Property Act CAP 509. All these laws and institutions have outlined the rules and procedures for some biotechnology application and development.

Kenya's resource commitment to S&T is rather low. The percentage of the R&D expenditure of the national budget is estimated to be in the range of 1.2% to 1.3% between 1984 and 1992 with much of the budget being allocated to KARI. There are other sources of funding such as from the Dutch government in a programme involving biotechnology applications in maize, biofertilisers, horticultural tissue culture, root and tuber and agroforestry (Tzotzos and Skryabin, 2001).

The outstanding feature of Kenya's biotechnology however is the political commitment at the top of government. In a letter to US President Bill Clinton, President Arap Moi requested American support for biotechnology capacity development. Among other things, he asked for support for "biotechnology training programmes, curriculum development and improvement of laboratories" (ISAAA website: www.isaaa.org/kc/Status/countries/kenya). That kind of political commitment at the highest level of government is bound to provide additional stimulus for the capacity building efforts.

7.10 South Africa

South Africa is the leading nation in sub-Saharan Africa in agricultural biotechnology. Monsanto South Africa is already propagating GMOs such as Bt Cotton and Bt maize. A GMO Act (Act 15, 1997) has been enacted and the framework for implementation has been laid out. The South African Committee for Genetic Experimentation (SAGENE) attended to the regulation of genetic engineering in the country. SAGENE gave way to an Executive Council. This Council receives, processes and decides on applications on GMOs. An Advisory Committee of scientists advises the Executive Council, Registrar and the General Public on matters relating to the application. The Ministry of Agriculture oversees adherence to the GMO Act and addresses related biosafety issues.

The first South African controlled field trial of genetically modified crops was done in 1992. In 1997, there was the first permit for commercial release. Currently, genetically modified crops are grown in the country. In the 1999-2000 season, commercial farmers cultivated a total of 163,000 hectares of GM maize and 18,000 hectares of GM cotton (Aerni, 2002, p.7). Genetically modified seed is the primary agricultural biotechnology import into South Africa. Genetically modified herbicide-resistant soyabean is the dominant preprocessed commercial GM product for consumption (Alhassan, 1999). The high level application of genetic engineering in crop agriculture shows the relative maturity of South Africa's biotechnology in the developing world.

A feature of the country's biotechnology system is the business operations of the transnational biotechnology corporations. Monsanto, Pioneer Hi-Bred International, Syngenta and Aventis are some of the well-known TNCs with investments in South Africa's biotechnology system. Almost all of them have created linkages with local South African companies to further their business interests (Aerni, 2002).

The main strength of South Africa biotechnology is the modern facilities available and the high level of expertise involved. About 60% of the agricultural biotechnology work force is women and this is in excess of 200. In fact, South Africa has become the regional centre of excellence for biotechnology training with the establishment of the UNESCO Biotechnology Education and Training Centre (BETCEN), which turns out large numbers of trained manpower from various African countries. Still there is the weakness of poor co-ordination of the "flurry of activities and the large numbers of players in agricultural biotechnology". More importantly, biotechnology does not appear to have trickled down to the average farmer level and there seems to be no arrangement to protect indigenous knowledge (Aerni, 2002).

Yet in a survey of public attitudes to agricultural biotechnology in South Africa, respondents recognised the significant potential of biotechnology in solving problems of drought, pest infestation, plant diseases and problems of low yields. However, respondents had "considerable reservations regarding the current biosafety regulation and its implementation" (Aerni, 2002). It does appear that in spite of the advancements South Africa has made in biotechnology development, there are a number of issues it needs to address effectively.

7.11 Japan

The commitment to science and technology in Japan came to the peak in the nineteenth century, with the country sending out its citizens to acquire scientific knowledge in the western countries. There was the realisation that, given the poor material resources available, the human resource offered the best opportunity for development through technological advancement. Japan has now achieved an extremely high scientific and technological status, which is one of the best in the world (http://www.jin.jcic.org.jp/today/science1.html).

The very high level of science and technology was attained through enormous public investment in the sector, which had increased over the years. In 1955 Japan's total spending on R&D was 40 billion yen, or 0.84% of the country's gross national product. This share was smaller than those of Germany, France, the U.K. and the U.S. However, by 1993 the spending on the R&D in Japan amounted to 13.4 trillion yen, which was 2.9% of the GNP. This was greater than the GNP shares of Germany, France, the U.K. and the U.S. The private sector accounts for about 79% of the R&D spending in Japan. The country has developed a large army of researchers of about

641,000 in 1994 and second only to the U.S. with 949,000 in 1989. The country has scored second to the U.S. by other scientific indicators of scientific advancement such as published papers in academic journals and number of patents registered. (http://www.jin.jcic.org.jp/today/science1html).

Biotechnology development in Japan is mainly geared towards medicine including regenerative medicine. Agricultural biotechnology products are very few mostly on account of the low intensity of agricultural in relation to manufacturing and other industrial sectors. The increase of biotechnology companies and their investments is almost exponential. For example, the trading house Mitsui and Company will increase its research investment aimed at developing new genetic testing and diagnosis technologies to over two billion yen in 2002, compared with 400 million in 2000. A total of 59.8% of biotechnology companies have planned to increase their R&D investment over the next five years (http://www.jin.jcic.org.jp/today/science1.html).

7.12 Germany

Germany was one of the first countries to create a national biotechnology programme with the government establishing Institute for Biotechnological Research - Gesellschaft fur Biotechnologische Forshung mbh in the mid-1970s. In 1989, the government initiated an umbrella programme called "Biotechnologie 2000" to encourage R&D and commercialisation of biotechnology. Between 1994 and 2000, an amount of $2.3 billion was expended on a wide range of biotechnology projects (Koehler, 1998).

The growth of the biotechnology sector in Germany is quite phenomenal the industry known to be doubling every 18 months. Government still provides support to the industry and at the existing rate of growth it is expected to within the decade overtake the biotechnology industry in the U.K., which is considered to be the largest in Europe. Being strong mainly in biotechnology medicine, it already has more genetically engineered medicine on the market than any other country in Europe.

Rigorous regulatory processes and antagonistic public opinion had obstructed biotechnology development in Europe in the 1980s and 1990s. Even though public opinion remains rather unfavourable, revised regulations had generally ameliorated the environment for biotechnology growth particularly in Germany. In 1998, Germany has 442 biotechnology companies compared to 1,036 companies in Europe and 1,274 in the U.S. Of the 442 companies, 75% was pharmaceutical though analysis of the market showed growing potential for agricultural application of biotechnology.

One of the important contributions to the growth in the biotechnology sector came from the federal states. The states granted permits for biotechnology research, production set-ups and field-testing. The states attitude toward biotechnology has been positive with most of them establishing offices and special programmes including venture capital for biotechnology development. For example the Heidelberg Technology Park houses an increasing number of start-ups and has become a science park for biotechnology. The state of Bavaria also provides infrastructure and space for new biotechnology business. It initiated the innovation programme known as the Offensive Zukunft Bayern with a venture capital of $90 million, a third of which went to biotechnology start-up companies. In 1996, Munich's Biotechnology Park was built with over 4,000 metre-square of rental space. The state of North Rhine-Westphalia like other states also has its own programme. Representatives from business, research, associations, chambers of commerce and politics assist in establishing biotechnology companies through the provision of information and a databank.

Germany's biotechnology application is also directed towards renewable resources. In 1995, the University of Hamburg field-tested a genetically modified variety of oil seed rape, which produced a higher content of erucic acid. The acid is used in the production of synthetic material in the chemical industries. In Europe, Germany leads in environmental application of biotechnology. It has 26% of the world's patents in environmental applications with the U.S. having 24%. Germany's strength is in its excellent research capabilities, its research institutions, and highly skilled and educated workforce. It has a very high reputation for scientific know-how deriving from excellent universities, the famous Institute for Biotechnological Research (GBF) in Braunschweig, the Max-Planck Institutes, the Fraunhofer Institutes, and the European Molecular Biology Laboratory in Heidenberg. With the scientific superiority, it has achieved exceptional efficiency. For example, Germany's 442 companies employ 11,000 workforce to generate sales of $1.18 billion whereas Europe's 1,036 companies employs a workforce of 39,000 to make sales of $3.16 billion. In the U.S., the 1,274 companies employ a workforce of 140,000 generating sales of $18.5 billion. Germany's main weakness is in the lack of private venture capital. Consequently, the federal states have partially filled the gap and entrepreneurs have also resorted to strategic alliances with American companies.

In the area of regulation, Germany's Genetic Engineering Act of 1st July 1990 incorporates a number of aspects of the European Union regulations such as the use of genetically modified organisms in industrial and research facilities, the release of GMOs into the environment and workers' safety. The Central Commission for Biological Safety is for biosafety classification of projects. Currently, there is a growing trend towards the relaxation of the previously stringent regulations to enable biotechnology industries to grown.

7.13 United States of America (US)

Whilst a proper review of the state of US biotechnology is too wide in scope to be done in this thesis, it is necessary that certain salient features with regard to trends in development, extent of application and regulation be highlighted. The US biotechnology is the most developed and most vibrant in the world. Of the 2,312 field trials of genetically modified crops in the countries of the Organisation for Economic Co-operation and Development (OECD) in 1998, the US accounted for 70% with countries such as Canada, France, Italy and Australia accounting for less than 10% (UNIDO BINAS website http://www.binas.unido.org).

Indeed in the US, over 5,000 field trials have been conducted since 1987 and about 40 new agricultural products have completed all the federal regulatory requirements from all relevant regulatory agencies (http://www.usda.gov.agencies/biotech). These range from longer-lasting tomatoes to pest-resistant corn. In a survey of the some of the states including Nebraska, Ohio, Illinois, Minnesota and Iowa it was found that in 1998, 30% of all crops harvested were genetically modified, increasing to 33% in 1999 (http://www.usda.gov.agencies/biotech). Some crops such as soyabean and corn are becoming completely transformed with the genetically modified varieties. The US accounts for much of the cultivation of many of these crops. For example, the US cultivates 63% of the total global area of genetically modified soyabean, 19% of genetically modified corn and 12% of genetically modified cotton. A recent survey showed that whereas the total global area of cultivated transgenic crops in 1999 was 98.6 million acres, the US cultivated a total of 71 million acres (http://www.usda.gov.agencies/biotech). Clearly, the application and diffusion of crop biotechnology at the highest technological level of genetic engineering in the US is unparalleled anywhere in the world.

The advancement of the America's biotechnology came as result of enormous investments in the technology. From 1983 to 1990, the US federal investment in biotechnology research was approximately $20 billion (Avramovic, 1996). Private investment through 1988 was about $10 billion with a further $4 billion being made between 1989 and 1990.The biotechnology industry is known to be spending about 43% of its product sales on R&D (Avramovic, 1996). As in Japan and Germany, the health sector dominates in biotechnology applications. For example, the top ten ag-biotech companies in the US had revenues of only $312 million in 1995 in contrast to the top ten pharmaceutical biotechnology companies having net sales of $4.3 billion (Avramovic, 1996). Nevertheless, unlike most advanced countries, the potential for agricultural biotechnology remains strong in the US particularly as enhanced regulations; government support and an improved public dialogue have contributed to creating the conducive environment for biotechnology application and development.

An important factor in the seemingly sustained superiority of US biotechnology is the high-level of skilled manpower that remain at the frontiers of the science and technology. To illustrate the superiority, of a total of 575 patents in genetic engineering registered in the US between 1973 and 1986, 68% were of US origin with Japan the second country accounting for 13% and the rest of the world accounting for 19% (Avramovic, 1996). Over the years, many of the advanced countries have woken up to the biotechnology challenge and have fairly caught up with the US in some areas. However, in the totality of biotechnology industry, the US remains unchallenged.

Apart from the highly skilled, there is a more aggressive business orientation to biotechnology in the US to the extent that the exportation and diffusion of biotechnology products particularly in agriculture has become central to US trade policy. Various business initiatives have played a pivotal role in the financing and marketing of the products of US worldwide. There have been joint ventures, equity purchases, marketing and licensing agreements, and contract research (Avramovic, 1996).

Three agencies are primarily responsible for biotechnology regulation in the U.S. namely, the United States Department of Agriculture (USDA), the Environmental Protection Agency (EPA) and the Food and Drug Administration. Though each of these agencies work independently, there is a close working relationship such that there is a well-coordinated system for biotechnology regulation. USDA's Animal and Plant Health Inspection Service (APHIS) is responsible for protecting American agriculture pests and diseases. The agency regulates the field-testing of genetically engineered plants and certain micro-organisms. Recent developments in US biotechnology regulations and legislation have led to the relaxation of the procedures for registration, assessment and approval for biotechnology products (USDA website: http://www.usda.gov/agencies/biotech). This is expected to sustain the leadership of the US biotechnology industry in the world.

7.14 Common Elements of Best Practice

There are a number of salient lessons from the review of biotechnology development in the developing countries as well as the advanced countries. From the various country experiences the following are the quintessential elements:

- adoption of a biotechnology programme/ policy/ strategy explicitly or implicitly
- establishment of biotechnology institution(s)
- establishment or review of the regulatory framework to address biosafety concerns, public investment in human resource development, physical facilities and and related components
- linkages with external biotechnology organisations and institutions
- commercial ventures in biotechnology with the participation of multinational companies
- involvement in regional collaboration.

In examining the experiences of other countries in biotechnology development, what stands out clearly is the significance of public policy in the development process. There must be a national programme for biotechnology application and development.

Whether implicitly or explicitly, public policy has contributed to capacity building even in the developing countries.

Indeed in the advanced countries, public policy has provided the framework not to mention the impetus for biotechnology development. The national programmes are as varied as the socio-economic and political contexts. Governments took the lead in terms of planning and resource allocation to ensure the development and application of biotechnology. National policy for biotechnology must be characterised by the identification of national needs, goal setting and prioritisation. There are various segments of the economy particularly in agriculture in which the application and development of biotechnology can impact. In the case of Malaysia biotechnology made impact on cash crops such as oil palm. India focused on among other things, biotechnology support for afforestation. Cuba used interferon production as a pivot for cross-sectorial capacity building on a commercial scale. Kenya's biotechnology is making impact on horticultural crops. All this illustrates the point about the need to focus biotechnology application and development with reference to the national development goals.

The definition of the public policy also went with resource allocation and the vital public investment in human resource development, infrastructure building and the development of the complementary components. The percentage of GNP or GDP allocation does not sufficiently expose the gross disparities in these allocations of, for example, Mexico and Kenya. The magnitude in real terms is what shows the different levels at which the public investments are made. However, the experience of the countries underscores the need for priority and focus on the critical needs in the national contexts.

The setting up of institutions responsible for biotechnology development is also another key element in the country experiences. Already established institutions such as research institutes and universities incorporate biotechnology applications in their activities. However, from India to Cuba the experience has been that a core institution is created to direct the biotechnology development agenda.

The creation of the necessary legislative and regulatory framework is an important factor in fostering the development of biotechnology. Risks assessment and monitoring cannot be done haphazardly. There must be the requisite guidelines and laid down procedures. Given the controversies surrounding biotechnology there is need for transparency in the commercialisation of its outputs. A properly constituted legislative and regulatory framework will enhance public confidence.

The creation of linkages with external institutions and organisations to solicit support for biotechnology development in the local context is also highlighted in the experiences of countries. Donor agencies and some of the advanced countries have been instrumental in building capacity in the developing countries. For example the signing of a scientific agreement for collaboration between Mexico and Japan in 1969 leading to the building of the first tissue culture laboratory at the Postgraduate College of Chapingo shows how developing countries can use international relations to build capacity in strategic areas. Most of these developing countries have created the necessary linkages to support their national efforts at building biotechnology capacity.

International collaboration is not limited to bilateral sources. There are a number of multi-lateral initiatives that have contributed to the development of capacity in the developing countries. For example the ICGEB based in India and Mexico has been instrumental in human resource development for developing countries. Research institutions such as CIMMYT of the CGIAR have contributed to executing biotechnology projects with the participation of developing countries for mutual benefits. In the UN system, UNESCO and UNIDO have also provided support for training and information dissemination.

The participation of the private sector is an important ingredient in biotechnology capacity building. This is one of the elements that stimulated capacity building in countries such as Kenya, South Africa and Zimbabwe. Quite often TNCs invest in the countries where their home countries have strong bilateral relations. For example the Japanese company Matsumoto invested in Mexico in 1972, establishing a tissue culture laboratory for the production of ornamental plants, following the Japan-Mexico agreement of 1969. Monsanto's business interests in Kenya is linked to the good relations between Kenya and the US.

The singular example of presidential commitment to biotechnology development in Kenya may be an added ingredient. The power of the office of the head of state in the developing world is without parallel. It will definitely benefit the country if that power is used to promote the advancement of biotechnology in strategic ways. That however should be on the basis that, the promotion will be in the national interests and that the concerns of all stakeholders will be addressed.

In reviewing the country experiences some of the factors causing failures have been highlighted. The lack of co-ordination in the various local initiatives inhibited progress in the Brazil despite enormous public investments. It is important that the issue of co-ordination be sufficiently addressed.

Again in Brazil, the controversies in Monsanto's commercialisation of the genetically modified soyabeans also highlight the need for transparency in the administration of the regulations. More importantly, there is the need to seriously address the concerns of other critical stakeholders such as the farmers and environmentalists.

7.15 The Gaps in Biotechnological Capacity Building in Ghana

The gaps in the biotechnology capacity of Ghana become evident based on the elements of best practice. There are gaps in the institutional and legislative framework, in the mechanisms for regulation, the linkages and investment. In assessing biotechnology development in Ghana, Alhassan (1999) notes that the activities in general have been fragmented and lack a national focus. There is no national definitive biosafety legislation under which genetically modified organisms (GMOs) can be developed or imported into the country. As shown in the review of the experiences of other countries, the legislative and regulatory framework is fairly well established for the development of biotechnology in most countries. This is necessary because, key stakeholders such as the TNCs and the scientists need to know the 'rules of the game'. More importantly, international regulations such as TRIPS and the Biosafety Protocol impose obligations on countries to institute the appropriate legislative and regulatory frameworks.

The main strength of Ghana's agricultural biotechnology is its highly trained manpower. In almost all the agricultural research institutions and the biological and agricultural faculties of the universities, there is expertise in some aspects of modern biotechnology including tissue culture and molecular biology as the core discipline or have received ancillary training in the areas. As shown in the results of the survey in chapter 4, there are institutions with the human resources but without the facilities for them to work. The gaps in the humanware however have to do with the lack of clearly defined and effective strategies for human resource development. Biotechnology studies have become graduate courses already in some of the developing countries. There are no such courses yet in Ghana. The biotechnology components of the existing curricula are also being conducted without adequate laboratory support. These are serious gaps that need to be addressed given the critical nature of the human resource for biotechnology development.

Indeed a major gap also relates to the weaknesses in the physical infrastructure. Laboratory and other infrastructure support services in agricultural biotechnology are grossly deficient. Tissue culture laboratories are not available in all the institutions that need them and where they are available, some of the complementary facilities are lacking (as discussed in Chapter 4). Molecular laboratories in particular are lacking in the university science departments and research institutes. These are absolutely essential for the high point of biotechnology, which is genetic engineering and therefore it is a major gap that needs to be addressed.

The deficiency in the physical facilities is however linked to the inadequacy of public investment. Government expenditure on R&D is only estimated to be about 0.1 of

GDP. Over the years, that expenditure has been dwindling. In the survey, it was found that, government budget supporting the biotechnology projects is generally around 25%. Alhassan (1999) also notes that all funding for agricultural biotechnology work is donor-sourced. Government needs to prioritise biotechnology development and give it the necessary attention in resource allocation.

Meanwhile biotechnology is diffusing globally especially in the agricultural sector. The acreage of GM cotton increased by 40% in 2000 - against an increase of 11% for all GM crops - and now covers a landmass of 5.3 million hectares or 6% of the 34 million hectares put under cotton cultivation worldwide (Dirham, 2000, p.8). Cotton is one of the most rapidly expanding transgenic crops. Bt cotton with the inserted gene from the bacterium *Bacillus thurigiensis* is considered the fastest adopted new product in the history of agriculture with the biggest increase in area of its cultivation occurring in the U.S. and China mainly, and also in Mexico, South Africa, Australia and Argentina. The global trend in the increasing diffusion of transgenic crops suggest that developing countries like Ghana need to create capacity for producing their own transgenic crops appropriate to their own local conditions. Developing countries must also put themselves in good stead to address the issues of importation of foreign transgenic crops. At present, Ghana's capacity is deficient either in terms of producing its own transgenic crops or addressing the issues of the global diffusion of transgenic crops.

The global commercialisation of transgenic crops poses many questions and contentious. For example Dinham (2000) noted, the question of whether GM cotton helps small farmers to reduce chemical dependence and whether the introduction of

Bt cotton could imply swapping one dependence for another would not be an easy question to answer. While GM crops may be grown under controlled conditions in the vast acreages of the US cotton belt, control is less possible in the small-scale plots farmed by agriculturalists in developing countries where the average cotton plot in India or Africa is well under one hectare (Dinham, 2000). It is only an enhanced biotechnology capacity developed in the national context that can address these issues appropriately.

The common elements of best practice as derived from the review of experiences of the other developing countries provide broad guidelines to arriving at a workable policy option for Ghana's biotechnology capacity building. There is the emphasis on the need to focus or define a goal and framework for biotechnology development. It may not be as explicitly done as in the case of Mexico or Brazil. However, in countries such as South Africa, Kenya and Zimbabwe, biotechnology has been identified as a strategic tool for achieving economic ends with reference to food and cash crops. It can be said that Ghana has also "identified" biotechnology as a critical tool in its development process and therefore it features reasonably in the implicit policies of the country (Essegbey *et al*, 1999). However it is one thing identifying biotechnology as a strategic tool and it is another thing actually working out the appropriate strategies and implementing them to apply biotechnology to the national development process.

For example, Ghana's biotechnology institution, BNARI, still lacks some of the critical facilities that can enable it make the necessary impact over more than a decade of R&D. The laboratory facilities for tissue culture do not have the supporting greenhouses and some of their equipment need repair. At present there is no molecular laboratory at BNARI. However, if BNARI should be the lead institution for Ghana as for example the Centre for Biological Research is for Cuba, then the institute has to be fully equipped and modernised. As shown in the review of the countries' experiences, a lead institution with the vital resources can effectively foster biotechnology advancement.

Clearly the point can be made that the state of the physical facilities, the information system, the approach to human resource development and the organisational framework for biotechnology activities in Ghana, compared with what prevail in other developing countries suggest that much more need to be done.

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CHAPTER 8

POLICY OPTIONS FOR BIOTECHNOLOGY DEVELOPMENT

8.1 Introduction

This chapter deals with the objective of generating policy options for the development, application and management of biotechnology for crop agriculture. It uses some of the major policy-related findings in the study to establish a basis for generating the policy options. These options are derived in connection with the four perspectives of technological capacity adopted for the analysis.

8.2 The National Development Goals

The over-arching goal of national development is the attainment of middle-income status through accelerated, sustainable and equitable growth (Ghana Government, 2001). The framework for reference in national development is the Ghana Poverty Reduction Strategy (GPRS). The implementation of the First Step of what is generally known as *Ghana Vision 2020,* beginning from 1996 to 2000, focused on economic growth, human development, rural development, urban development and the enabling environment. Whereas some verifiable results were attained including an average GDP growth rate of 4.3% during the period and an improvement in social amenities in the rural areas, the incidence of poverty was unsatisfactory. Ghana's current poverty situation is estimated to be 36% of the population falling below the national poverty line and 40% falling below an income of one-dollar daily wage. Thus, the overall goal of the GPRS is "the virtual disappearance of poverty by 2020" (Ghana Government, 2002a)." Some of the pillars identified for the implementation of the Strategy include the following:

- rural transformation through agricultural reform,
- agro-based industrial revolution through agricultural transformation,
- accelerated vocational and technical training for the informal agricultural sector.

In this regard, public policy for biotechnology development must facilitate the attainment of the goal of poverty elimination in the long term, and move the country into the middle-income bracket. The question is what initiatives can be derived from the GPRS to ensure that biotechnology makes a positive impact on the process of development. Finding an answer to this should begin from the adoption of a multi-dimensional approach, which will integrate the interests and competence of the identifiable stakeholders or actors. To this end, the National Stakeholders' Conference of 1999 made important recommendations including:

- building capacity in identifiable biotechnology institutions,
- formulating human resource development strategies,
- setting up a National Biosafety Committee to address issues of regulation and monitoring,
- prioritising the characterisation of Ghana's genetic resources of the biodiversity (Essegbey *et al*, 1999).

In sum, stakeholders expect capacity building across the four components of technoware, humanware, inforware and organoware (refer conceptual framework). However, to these generalities of proposals, what have emerged from this thesis are important principles that should undergird the public policy for biotechnology application, development and management. These are:

- The application and use of biotechnology as a generic tool should be in consonance with the national development goals and other sectoral policy objectives and must be adapted to address specific problems within the national context.
- The application of biotechnology should be on the precautionary basis that there are possibilities for negative impact on human health and on the environment and therefore the necessary counter measures would be put in place to enhance biosafety.
- In the scheme of national priorities, biotechnology development must rank high in terms of resource allocation for capacity building.
- The development of biotechnology should be holistic and cross-sectoral to enhance synergy of impacts and the free flow of knowledge and competence.

In this connection, the chapter discusses the various areas and ways in which the stated principles can be operationalised highlighting the envisaged holistic approach to a national biotechnology programme or policy.

8.3 Educational Policy

The Ministry of Education in its *Policies and Strategic Plans for the Education Sector*, states that, "emphasising the study of science and technology is a constitutional requirement in Ghana. Studies have confirmed a significant positive relationship between the proportion of college students majoring in various disciplines in science, technology and engineering and subsequent real growth in GDP per capita. The tertiary sector will link up with the basic level in promoting science and mathematics education to ensure that many more students are available to study science at the tertiary level" (Ministry of Education, 2001, p.78). Key strategies for achieving the objectives are:

- Restructuring of enrolment and output of tertiary institutions to achieve a science –arts ratio of 60 to 40 in relation to national needs;
- Improving academic and physical infrastructure such as laboratories and equipment to promote the teaching and learning of science and related disciplines;
- Introducing a system of incentives and motivation to attract and retain science teachers;
- Generating interest in and encouraging the study of science through scholarships and loan schemes (Ministry of Education, 2001).

To achieve the improved enrolment in S&T–related courses, the following activities were specified:

- Organisation of enrolment drive and workshops using role models to sensitise potential science students including females;
- Counseling and guidance programmes pursued;
- Complete on-going construction and rehabilitation of science and technological projects;
- Provide science consumables and materials;
- Provide science equipment and plants (Ministry of Education, 2001).

The educational goals and objectives as stated above provide a framework for developing a holistic policy for the creation of *human capital* in biotechnology. From the survey of the NARS, there is available a significant number of scientists with training up to the level of Ph.D. in biotechnology-related disciplines such as crop breeding, soil science, plant pathology and molecular biology. However, these only enable the country to carry out projects that tend not to make any remarkable impact on the problems affecting the country. As it were, the scientific corps available can only provide a basis for drawing a more detailed HRD programme within a framework of a biotechnology strategy. Besides, the training of manpower should never be the end but rather the means to achieve strategic goals.

For example, Cuba's entry into modern biotechnology industrial application was facilitated by the already existing scientific capabilities, which were working at the National Centre for Scientific Research (CENIC). They did not start *ab initio*. They were young post-Cuban revolution scientists who studied abroad in countries such as France and Russia and who were able to master the state of the art techniques. When Cuba decided to adopt interferon production as a strategic national objective, the scientists were already working on yeast fermentation, which was being applied to produce single cell proteins (SCP) from sugarcane derivatives. From 10 plants the country produced 12,000 tons of SCP to be used as soya substitute for animal feed (Fransman, 1991, pp.62-63). In short, Cuba had a successful entry into industrial modern biotechnology on the basis of a corps of scientists with the training, competence and motivation. The experiences of other countries such as India, Brazil and Kenya show that the development and motivation of the human resource is critical to launching a successful biotechnology programme.

Fortunately the Education Policy document is meant for "policy dialogue" with society in general, and with particular groups (Ministry of Education, 2001). If the dialogue process is dynamic, it may have room to take on board some suggestions to address the issues raised in this thesis. An important question to address is how to situate HRD for biotechnology development in the prevailing scheme of things. The document itself notes the inadequacy of training in the various sectors. There is an insufficient number of graduate and postgraduate degree holders in key posts. More local and overseas postgraduate training in relevant skills will be required. The policy strategy is therefore to use training opportunities as key incentive, which would be "linked to performance" (Ministry of Education, 2001). But the strategy has to move from the point of generality to points of specificity. It is not so much the issue of sectoral prioritisation as how to ensure effective and efficient allocation and utilisation of resources for crosscutting capacity building.

HRD for biotechnology is essentially at tertiary level. But the tertiary level has only 12-13% of the education budget. The education budget is also only about 4% of GDP (Ministry of Education, 2001). The current bias for pre-tertiary education, which takes 80% of the education budget, is in line with the constitutional provisions. Article 25 of the constitution states inter alia:

- basic education is free, compulsory and available to all;
- secondary education, including TVET, is to be generally available and accessible, and will be progressively made free (Ghana Government, 1992b, article 25).

Pre-tertiary education is good and it contributes to creating an informed and educated climate for biotechnology development. But it does not lead to the kind of human capital formation that feeds into technological innovations and applications. The most important factor markets is technology. At the heart of technology are the technical and innovative skills. So governments must promote education and training and it must be done at the higher or tertiary level where quality human capital formation prevails. But even as they do this, it must be noted "policies to promote development become fairly selective at higher levels" (Lall, 2001) Biotechnology development is a priority and therefore, there must be the selective concentration of resources and strategies on training at the higher levels of education.

However, the issue is whether the chicken comes before the egg or the egg before the chicken. Should there be a biotechnology policy to precede an HRD for biotechnology or vice versa? For a national biotechnology programme to be implementable, it should draw on available capabilities and competence within the NIS as far as possible. As the schema in figure 8.1 will illustrate, biotechnology policy should be a crystallisation of the signals impinging from various sources on a contextual template of specific needs. These sources are endogenous and exogenous to the national context. The existing human resource or competence, for that matter, should not be the sole basis for the programme. For example, an important basis is the drive to enhance the competitiveness of the country. In this regard, there may be stated objectives that may require additional capabilities and competence unavailable or inadequate in the NIS. Thus the relationship between the human capital formation process and the biotechnology programme formulation process should be that of cross-reference. There should be a feedback into each other to ensure effectiveness.

8.4 The S&T Policy

The National Science and Technology Policy spelt out three basic goals derived from the national development vision for the use and efficient management of S&T in Ghana. These are:

- The establishment of a well-coordinated and integrated system of scientific, technological and social innovation within which public and private stakeholders can interact in an inclusive and consultative approach concerning decision making and resource allocation for scientific and technological activities.
- The encouragement of a culture within which the advancement of knowledge is valued as an essential component of national development.
- Improved support for all kinds of innovation, which are fundamental to sustainable economic growth, employment and socio-cultural development (MEST, 2000).

The S&T policy goes on to state a commitment to the promotion of S&T innovation and enhancing endogenous capacity for selecting, acquiring, adapting and absorbing imported technologies appropriate to national needs, priorities and resources.

However, it is a matter of disappointment that, the specific subject of biotechnology development was only reduced to a policy strategy of promoting "the research and application of new technologies including biotechnology – genetic engineering, etc. – which hold potential for increasing productivity" (MEST, 2000). Granted that the S&T policy simply outlines the framework for S&T application and development, there is the need to focus on the key components and elaborate. Biotechnology as a critical tool for economic development and for optimising performance of the agricultural sector as well as other sectors needs a comprehensive programme developed through the stated inclusive and consultative approach. It is best to analyse and formulate strategies for biotechnology as a set of technologies with application to a large number of product areas. The process technologies include classical methods of selection, recombinant DNA techniques, cell fusion, tissue culture, protein engineering, and bioprocessing. The combination of these technologies may be applied to the research and development of a large number of products (Fransman, 1991, p.67). Thus the development of biotechnology generally can be best done within the framework of a national programme or policy.

8.5 Agricultural Policy

The findings of the thesis reflect the generally known constraints in the agricultural sector. The sector is dominated by small-scale, typically subsistence farmers lacking in resources with an average of small size holdings of up to two acres. There is a low adoption of the scientific inputs of fertilizers, pesticides and weedicides due to price constraints given the low incomes farmers derive from their occupation.

Over the years the government undertook various policies for the improvement of the agricultural sector and to specifically address the constraints. For example the medium term agricultural development plan (MTADP) and the National Agricultural Research Programme (NARP) were implemented in the 1990s to improve the performance of the sector. The current plan is the Accelerated Agricultural Growth and Development Strategy (AAGDS) spanning over a ten-year period (1997 –2007). It aims at increasing the production of selected products through, among other things, the improvement of access to technology for sustainable resource management, enhancing human resource and institutional capacity. There is also the International Fund for Agricultural Development (IFAD) as well as the newly developed Food and Agricultural Sector Development Programme (FASDEP). The main instrument for implementing some of the economic programmes is however the Agricultural Services Sub-sector Investment Programme (AgSSIP). A key strategy to increase food production in the short and medium term is to promote selected commodities on the basis of food security, agricultural raw material for industry and commodities for export. There is also the Root and Tuber Improvement Programme under which in 2002, there would be supply of cassava planting materials for multiplication and use to a projected 50,000 farmers (Ghana Government, 2002b).

All these plans and programmes provide opportunities for linkage with biotechnology development. Already, some of the institutions such as BNARI and Crops Research Institute are connected to some of these programmes as for example in the production of planting materials. However, there is need for strategic emphasis and a commitment to institutionalise the delivery of scientific inputs into the production processes. What is more, these initiatives may not be able to achieve much if it does not address the issues in the flow of innovations from the supply side to the demand side are not addressed. To achieve this, there is need to among other things:

- improve capacity of the NIS through an upgrading of physical facilities, the training of human resources and the provision of resources for R&D activities and for extension;

- re-orientate the incentive system in agricultural R&D towards more active transfer to the user farmers through the demonstrations and organisation of farmers schools on innovations;
- promote use of scientific inputs through the provision of financial schemes to enable farmers gain access to inputs.

There are also specific strategies that the agricultural policy should adopt to address the market failures. Crop production is not merely an economic concern. It is also a socio-political concern. It is about empowerment of the under-privileged and under-resourced people of the society and it is about sustainability of livelihoods.

Naturally, the world economic regime has changed since the international community established the WTO. The regulatory and monitory regime for international trade has become stronger and it is less easy for governments to carry through interventionist policies. Still there are ways countries pursue interventionist policies including the advanced countries such as the U.S. and the U.K. In the areas of skill formation and R&D, countries have the opportunity to intervene positively for technological capacity development (Lall, 2001, p.23). Therefore the argument being reiterated here is that, agricultural policies could draw on strategies for building biotechnology capacity, which can impact positively on agriculture in the country.

Another crucial challenge for agricultural policy to address is the institutional framework for transfer of innovations from the scientific institutions to the farms. The traditional "top down" model for innovation transfer appears inadequate. Some have gone as far as stating that the organisational form of the traditional extension system is inherently not viable and will have to be replaced (Chambers *et al*, 1989). But as Clark (2001) has pointed out, the lack of technological development in Third World agriculture is not something reducible to simple solutions of providing financial support. Nor is it due solely to lack of research skills since much more could be made of existing capacities. What are really needed are "institutional structures that permit the symbiosis of knowledge search with knowledge use" (Clark, 2001, p.30). In the deployment of biotechnology to address the country's agricultural problems, meeting this need is an enormous challenge.

8.6 Economic Policy

Since the introduction of the economic liberalisation policy in 1983, Ghana has kept faith with the philosophy that 'the market best controls economic activities'. With the support of the Bretton Woods institutions, Ghana has implemented various policies and strategies to maintain the laissez-faire market economic system. The Economic Recovery Programme (1983) Structural Adjustment Programme (1986), the Private Sector Development Programme (1994) and the National Institutional Renewal Programme (1999) are examples of programmes that aimed at reducing government participation in the economy and creating incentives for the private sector to lead in economic performance. The trend has not changed and one may expect national economic policies and strategies to be informed more by the philosophy of private-led participation with the present declaration of Ghana's golden age of business.

The liberalised economic regime only creates the climate but the key to prosperity in the increasingly globalised and integrated international economy is *competitiveness*. The country has to put in place the necessary policies to enhance competitiveness.

The libertarian neo-classical notion that the market must run the economy and that governments should stay completely away from market and if they do, then development can take place is not backed by the evidence of development of countries. The Asian tigers are only the latest in a long list of countries that developed only by pursuing interventionist policies (Lall, 2001). This thesis cannot go outside its scope into the arguments for or against intervention and the intricate details of the interventionist policies that ought to be in place. It is a subject, which is best handled upon further research and discourse. The thesis can only suggest ways in which government can improve the economic policy environment to facilitate technology application and development.

Given the past unfortunate attempts in state-led industrialisation, Ghana should promote conditions that would enable the private sector to lead in the economic resuscitation. However, this should not exclude state intervention to enhance the competitiveness of the private sector particularly where it concerns the application of S&T and creating the technological capacity to sustain private business and enterprise. In this regard as Mytelka (1999) pointed out, there are no simple rules for and there can be only “rough guidelines”. The key questions are:

- What are the main “drivers” of competitiveness including the different causal factors at any given time?
- To what extent is innovation necessary for competition? (One has to understand the specificity of the particular industry at a point in time and determine what kinds of innovations are necessary)
- Are the innovation processes that are necessary already taking place effectively under existing circumstances? (If no, what

policies are needed to facilitate the necessary innovation processes).

- Will increased competition result in the kind of innovation that is necessary? (If yes, how can it be created? If no, what conditions are needed to produce these innovations?) (Mytelka, 1999)

Generally, the NIS should be at the centre of the economic strategies to foster economic growth. For example, the present efforts to diversify the country's economy and reduce the foreign exchange earning component of cocoa should be linked to the national innovation process. While some initiatives already are in evidence such as the developments of new cocoa products at the Cocoa Research Institute and the Root and Tuber initiative supplying planting materials for the President's Special Initiative on Cassava (Ghana Government, 2002a), there is need for invigoration. Some of these initiatives need strengthening and in some cases, there is need for revision with regards to objectives and modus operandi.

But more importantly, in the dynamic new technology era, these initiatives are, to say the least, not enough. Cassava, or for that matter agricultural commodity-specific initiatives, may not offer the vital range of options for diversification on the international market. The bottom-line should be a wide range of competitive innovated and value-added products on both the domestic and international markets that contributes to economic growth. Again, it boils down to formulating a vision for the generic biotechnology and strategising for the achievement of that vision.

It is in this regard that a holistic development of biotechnology is vital. That holistic approach is necessary given that biotechnology is an interrelated set of technologies, which is having and will continue to have a pervasive effect on a large number of economic sectors (Lall, 2001). In the areas of agriculture, industry and health the impact is diffusing internationally with new products of crops, foods and drugs. It is a matter of strategic interest for Ghana to develop capacity in biotechnology.

8.7 Biotechnology Regulation and Monitoring

The need for capacity building in biotechnology also implies the need for anticipatory policies to address safety concerns pertaining to human health and the environment in the application of biotechnology. Despite the fairly long development of biotechnology, the uncertainty of the potential impact on human health and the environment demands that measures be put in place to address risks. Regulation and legislation provide the precautionary basis for biotechnology application and erect the fundamental fence of biosafety.

Apart from being a requirement for all countries that have ratified the CBD (as Ghana did), it is important for a developing country to put in place measures to prevent any possible risk with biotechnology application. Developing countries have fewer resources to deal with the inestimable negative impacts of biotechnology applications. As part of the agenda for setting the stage for the implementation of the articles of the CBD, an open-ended ad hoc Working Group on Biosafety was set up under the auspices of the Conference of Parties of the CBD. It was to deliberate on ways of identifying the elements for a biosafety protocol. To prepare developing countries to benefit from these meetings of the working group on biosafety, several workshops were organised. The International Academy of the Environment (IAE), the West African Rice Development Association (WARDA) and United Nations Environment Programme (UNEP) organised a workshop for selected West and Central African countries between 10th and 14th June 1996 in Abidjan, Cote d'Ivoire. After this meeting, the Ghanaian participants formulated some guidelines on biosafety for the attention of the Ministry of Environment, Science and Technology (MEST). For a long time there was no concrete action on the draft submitted to MEST. In November 1998, the Ghana Institute of Biology organised a national workshop to deliberate on Ghanaian biotechnology, and in particular discuss the proposed guidelines.

STEPRI had also initiated biotechnology policy studies in 1997 with emphasis on biosafety (Essegbey, 1997). In December 1999 it organised a National Stakeholders' Conference on Biotechnology in collaboration with BNARI and the GSES of the University of Strathclyde under the Biotechnology Development Programme. The key stakeholders including scientists, policy-makers, farmers and non-governmental workers participated. One of the key recommendations was the formulation of a biosafety regime for Ghana.

Following these initiatives, MEST set up an 18-member National Biosafety Committee under the chairmanship of the Chief Director and inaugurated it in April, 2000 with the following terms of reference:

- Formulation of policies, regulations and procedures for biosafety in the country.
- Coordinating and monitoring biotechnology activities in the country.
- Development of human and institutional capacity in biosafety; and

- Coordinating Ghana's participation in global and regional discussion on biosafety (Oteng-Yeboah, 2001).

Membership of the Committee was drawn from stakeholder ministries and organisations including MEST, MOFA, C.S.I.R., EPA, the universities and CEPS. With the inauguration of the National Biosafety Committee, it is expected that the necessary steps will be taken to address the terms of reference.

The participation of Ghana in the global debate on the issues of biosafety is very important. The controversy that the debate has generated since the setting up of the Conference of Parties in 1992 to produce the biosafety protocol for the international community signifies the differences in the interests of the individual countries. In January 2000, a total of 130 countries including Ghana eventually agreed to the final text of the Cartagena Protocol on Biosafety. Basically the protocol seeks to protect biological diversity from the potential risks posed by the genetically modified organisms resulting from modern biotechnology (Website: www.biodiv.org/biosafety). The 40 articles and three annexes of the protocol among other things established an advance informed agreement (AIA) procedure for ensuring that countries provide relevant information necessary for informed decisions concerning the import of GMOs. It also adopted the precautionary principle, which states that "...where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation" (Website: www.biodiv.org/biosafety).

What is important in all this is the need for international collaboration in matters of regulation, monitoring and prevention of risk in biotechnology application and development. Ghana cannot be self-sufficient in risk assessment, containment and management. It has not got the totality of the scientific knowledge and the resources to do this. It is doubtful whether any country in the world including the leading biotechnology country, the U.S., has the full complements for total biosafety. Therefore there is need for international collaboration. The extent of national interests creating conflictual situations in the negotiation process suggests the need to strongly collaborate with sister developing countries in matters of biosafety. During the negotiations, countries advanced in biotechnology such as the U.S. were seen to be pushing for less stringent regulations as opposed to the developing countries, which were concerned about potential deleterious impacts in their countries. Ghana and other developing countries should work within the scope of the CBD to address issues of capacity building in areas of scientific applications, risk assessment, monitoring and regulation for biosafety.

Biosafety concerns the safety of biological material in the environment, and hence biosafety regulations are focused on the direct biological consequences of introducing GMOs into the environment (Persley et al, 1992). Thus it addresses three questions:

- What is the nature of the organism to be released?
- What is the environment where it is to be released?
- What is the likely species interaction?

These pertain to the direct consequences of the release of biotechnological materials into the environment. There are however more complex effects and a typology of the consequences fall into:

- direct (biological, ecological, evolutionary, i.e. the scope of biosafety)
- indirect (consequences of the deployment of a new technology), and
- secondary (sociological and socio-economic, related to the development of a new technology) (Persley *et al*, 1992).

The fundamental question for the Convention on Biodiversity is how best to adopt, utilise and harmonise biosafety regulatory mechanisms that protect biodiversity and the environment without hindering access to the technologies sought by developing countries. It is important that even after the passage of the biosafety protocol, the developing countries undertake capacity building to implement the protocol and ensure biosafety in their respective contexts.

8.8 Intellectual Property Regime

The development of biotechnology has generally moved in tandem with the development of intellectual property. Whereas previously the principle underlying intellectual property regimes was that living organisms or their parts could not be patented, developments in biotechnology have necessitated the protection of life-forms. Indeed the Trade Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organisation (WTO) require all parties to "provide for the protection of plant varieties either by patents or by an effective *sui generis* system or by any combination thereof" (Ghijsen, 1998, p.3-5). Ghana therefore has to institute the necessary regime to satisfy the WTO provisions.

One of the widely used systems for the protection of plant varieties is operated under the International Convention for the Protection of New Varieties of Plants – UPOV Convention (1961, 1972, 1978 and 1991). The system evolved in the first half of the twentieth century when advancement in agricultural practices created farmer demands for new planting varieties in Western Europe. Already, the patent system was in operation under the Paris Convention for the Protection of Industrial Property of 1883. However, the patent system was found to be too rigid and inflexible for the protection of plant varieties. The patent system actually proscribed the patenting of living things (Ghana Government, 1992a). From original-founding members of four - Germany, France, the Netherlands and Belgium - UPOV currently has 50 countries that have acceded (website: www.upov.int). It appears to be addressing its mission to provide and promote an effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants. The various revisions of the 1961 convention were done to address more effectively the need to provide incentive for breeders in the same way as for inventors and authors. The 1991 Act in particular which entered into force in 1998 was developed in response to the technological developments in plant breeding to address issues such as striking a balance between the needs of breeders, farmers and other plant variety users. However, in spite of the efforts to address the issues, there are criticisms against the UPOV system particularly in respect of the rights of farmers who through the practice of saving seeds have preserved important genetic resources for plant breeders. The system seems to be conceptually in conflict with farmers' rights as defined by the FAO Conference Resolution of 1989 (5/89). It states that farmers' rights are "…rights arising from the past, present and future contributions in conserving, improving and making available Plant Genetic Resources (PGRs), particularly those in the centres of origin/ diversity" (ibid). The UPOV system cannot recognise "past, present and future contributions" of farmers since it is intended to give proprietary rights to those who develop new plant varieties, which meet the technical criteria of distinctiveness, uniformity and stability of the variety (Seiler, 1998).

Meanwhile, the changes in the intellectual property regime brought about by developments in biotechnology have also opened the door for plant varieties in the patent system. In the developed countries, particularly in the US, the patent system is being used to protect GMOs and to protect specific genes. It complicates the issues with regard to access to genetic resources and benefits to the original sources the genetic resources. The TRIPS agreement however imposes obligations on all countries to "...provide for the protection of plant varieties either by patents or by an effective *sui generis* system or by any combination thereof" (Seiler, 1998). This does not however mean that countries should compulsorily accede to the UPOV or the patent system. Member countries therefore have the option to:

- make provisions for the plant protection of plant varieties,
- join the UPOV system
- provide for comparable plant variety protection outside the UPOV system
- devise a *sui generis* system better suited to national interests taking into account the needs of informal and local communities (Seiler, 1998).

Ghana is in the process of acceding to the UPOV with draft legislation being prepared for parliament (Personal Communication, 2001). What this means is that Ghana is opting for a more rigid and rather mechanistic treatment of proprietary rights relating to genetic resources. Naturally, it serves the purposes of plant breeders and transnational corporations who have already obtained such rights in the advanced countries. However, it virtually comes against the concept of farmers' rights and runs the risk of facilitating the free exploitation of Ghana's genetic resources by foreign interests. Developing a *sui generis* system is difficult but it is more beneficial to the country. For example, India passed three parliamentary acts to protect its biodiversity, the interest of plant breeders and the farmers. These are the Protection of Plant Varieties and Farmers' Rights Act 2001, the Biodiversity Act 2001 and the Geographical Indication of Goods (Registration and Protection) Act 1999. Apart from enabling India to meet the obligations of TRIPS, these acts have also provided a means for India to challenge some of the frivolous proprietary rights given to transnational corporations in the advanced countries (Choudhary, 2001). Ghana may need to examine again the proposed legislation and ensure that the instituted intellectual property regime addresses the interests of the nation and all stakeholders.

Indeed the issues relating to intellectual property in biotechnology are controversial and far-reaching bordering on national interests and the interests of critical stakeholders particularly the small-scale farmers. The case of the Texamati rice illustrates the point. The US patent administration granted a patent to an American company called RiceTec Inc. covering Basmati rice lines and grains. But Basmati rice is an existing variety of rice of Indian and Pakistani origins, the result of over centuries of cultivation. Currently, there are about one quarter million farmers growing Basmati rice in India and Paskistan (Shiva, 2002). Yet the American company was able to obtain proprietary rights. Another case in point is the potential legal threat against ordinary farmers who may unwittingly be growing patented crops. The classic case illustrating this is the *Monsanto versus Schmeiser* case, which came up in 1999 in the Canadian courts. Monsanto, one of the leading transnational biotechnology corporations took a farmer to court for growing canola crops containing Monsanto's patented gene for resistance to Roundup Ready herbicide. The farmer's defence was that he usually planted saved seeds from his own farm and that if the patented gene was present then it must be the result of cross-pollination with the genetically modified crops grown nearby. But the court found farmer Schmeiser guilty and fined him $20,000. Indeed court cases against farmers are going on in the US and Canada and can go on in any part of the world where the intellectual property system does not sufficiently protect 'innocent' farmers. In this regard, it is important that Ghana's intellectual property regime should be formulated to address these issues.

Formulating the appropriate intellectual property regime provides only a part of the answer to the issues raised. There are other dimensions involving technical means of safeguarding intellectual property such as the use of "genetic use restriction technologies" (GURT). As Swanson (2002) pointed out, GURTs are a natural consequence of the technological progress of the biotechnology revolution, which provide solutions to the so-called problem of "durable goods monopoly". Given the persistent biotic and abiotic stresses in the farmlands of developing countries, GURT represents a novel innovation for the investor for "rent capture" (Swanson, 2002). Goeschl and Swanson analysed for 86 developing countries in six crops and made simulations for GURTs over a 20-year timeframe. On that basis they predicted that GURT would have a negative impact on the rate of diffusion of innovations in those crops for which developing countries would have to rely on innovations from abroad. This is because the advanced germplasm incorporated within those commercial cultivars would be more costly to reproduce and disseminate. GURTs therefore present a challenge to the global regulation of biotechnologies and to "the role of the public sector in generating and diffusing productivity gains" (Swanson, 2002). However, the deployment of GURT has implications for subsistence farming not simply because farmers will be tied to seed purchases for every planting season, but also because the genes that restrict the use may cross into the indigenous varieties. The solution may not come merely by regulating against the technology with the appropriate legislative instruments but developing the scientific capacity to produce seeds for farmers that will enable them to avoid seeds with GURT.

8.9 International Collaboration

There are various ways of taking advantage of the mechanisms for international collaboration to build capacity in biotechnology application and development. These are:

- bilateral support for biotechnology programmes
- multilateral arrangements for biotechnology programmes
- promoting institutional collaborations with institutions with mutual interests in foreign countries
- regional and sub-regional initiatives.

This thesis has highlighted a number of initiatives that have been supported within the framework of Ghana's foreign relations with various countries. For example the DFID, USAID, CIDA and other donor agencies of friendly countries have at one time or the other supported initiatives that contributed to Ghana's biotechnology capacity development through supply of equipment, training and information systems. The research has also highlighted the institutional initiatives that have enabled local institutions to create the kind of capacity they possess. Regional institutions such as the IITA and WARDA have also played roles in capacity building especially in the area of training in the same manner as the UN agencies such as the IAEA and ICGEB. What needs to be done however is to scale up some of these initiatives to priority programmes of the country and for greater commitment at top level of government to elicit greater support from friendly countries. For example, President Daniel Arap Moi wrote to President Bill Clinton of the U.S. requesting support for Kenya's biotechnology programmes in areas of training, "curriculum development and improvement of laboratories" (ISAAA website). This kind of top-level commitment is what is needed to move biotechnology upwards on the gradient of development.

8.10 Private Sector Policy

The private sector policy is synonymous to the investment policy of the country inasmuch as it is linked to the pursuit of private-sector-led economic growth. One of the new initiatives is the creation of the Ministry of Private Sector Development (MPSD), which has the responsibility of undertaking programmes that would enhance the participation of the private sector in Ghana's economy. The effectiveness of the new ministry will depend to a large extent on the linkages it is able to establish between itself and the other key institutional actors such as the Ghana Export Promotion Council and the Ghana Investment Promotion Centre (GIPC).

The GIPC 1994 Act, which sets up the GIPC, provides the legislative and policy framework for investment in the country including addressing issues of regulations, procedures for investment and business ownership structures. With respect to incentives for investors, there are provisions for exemptions from taxes, capital allowances and concessions in cases of losses. These are important policy instruments that governments generally use to stimulate investment and private participation in desirable economic sectors. However as technology policy instruments, there is need to go beyond that and indicate potential areas.

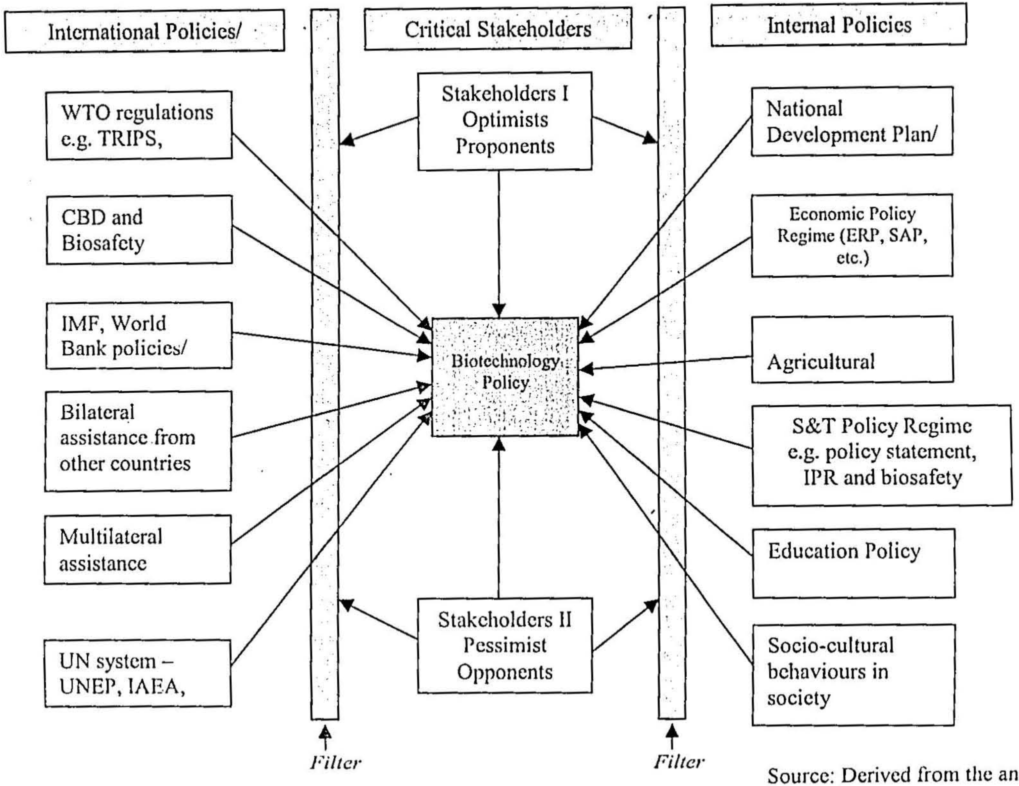
For example, this thesis notes the interest of some farmers in adopting tissue culture to support their commercial farming for pineapple exports (Personal Communication, 2000). Already the Volta River Estates Ltd., which exports banana to Europe uses, imported tissue cultured planting materials to develop the estates. Some pineapple exporters have also shown interest in using tissue culture to enhance their exports. There are indications that some entrepreneurs in Ghana intended to go into private commercial tissue culture services but did not get the venture capital. It is a contrast to the situation in Kenya and South Africa, for example, where tissue culture services have linked up with crop production. In the case of Kenya, tissue culture was even instrumental in a successful banana project aimed at enhancing the livelihood for small-scale farmers (Wambugu, 2001). Biotechnology is a tool that can be used at the discretion of the owner. Policy makers have a duty to create the environment for its beneficial use in line with the national economic objectives.

8.11 Biotechnology Policy for Ghana – The Options

The categorical position that Ghana needs a Biotechnology Policy may not necessarily be the logical conclusion of this thesis. In the fundamental sense, that was not what the thesis set out to research. But there are related questions, which though do not demand categorical answers in terms of "to be or not to be", raise issues of the relevance of a biotechnology policy. This thesis has dwelt at length on the fact that in the experiences of countries that have advanced comparatively in biotechnology, there has been a formulation of a national biotechnology programme. The national programme for biotechnology development may be based on an implicit or explicit biotechnology policy. What is however important is the commitment that went with the programming and the transmission of that commitment into various levels of stakeholder activities for biotechnology development. Therefore at the fundamental level, this thesis concludes that it is important for Ghana to have a strategic framework for biotechnology capacity building and ensure commitment across the various facets of policy formulation, implementation, monitoring and evaluation.

More importantly, the bedrock of the conceptual framework of the thesis is the proposition that the *whole is greater than the sum of the parts*. This chapter has highlighted the elements in the various national policies that have related to biotechnology in terms of infrastructure building, human resource development, the institutional and regulatory framework, among others. What needs to be emphasised is the need to consolidate the goals and objectives as well as the various activities to achieve the necessary synergy in biotechnology development. In this regard, there is need for a biotechnology programme or framework derived from a holistic approach as illustrated in Figure 8.1.

Figure 8.1 Schema of Biotechnology Policy Formulation Process



Source: Derived from the analysis of the thesis data

The process for arriving at this strategic framework, which is here conveniently termed biotechnology policy, is important for the commitment of stakeholders. In the schema on biotechnology policy in figure 8.1, the various signals from exogenous and endogenous sources impinge on a template in the national context. There are filters in the radiation of the signals because it is not every signal in the sources that is wholly taken in. These sources – the national and sectoral policies of the country and the operative international regimes in the respective socio-economic and political arenas – are important to the extent that they emit signals that get absorbed into the biotechnology policy.

The point about the schema is to illustrate the multi-dimensional considerations that have to inform the crystallisation of the national biotechnology programme. The various groups of stakeholders are classified broadly into the Optimist group and the Pessimist group mainly to highlight the perspectives they will be bringing into the discussions. The Optimists usually are the scientists, researchers and academicians and they emphasise on the potential benefits of the technology. The Pessimists who usually are the non-governmental organisations such as Friends of the Earth and Greenpeace bring into the debate the need for measures against the risks that go with the application of biotechnology. The division into the two broad groupings is deliberately done to underscore the need to approach biotechnology programming from different perspectives - especially from technically "antagonistic" perspectives.

The discussions about how to make technology policies or strategies more effective in developing countries have been going on for quite a long time. What seems to have achieved consensus is the strategy of insuring adequate participation of "stakeholders" in arriving at social decisions both about technology choices and about alternative paths of technology development (Brooks, 1992). The term "stakeholders" refers to suppliers as well as consumers of technology and extends also to agents of technology development or adoption such as non-governmental organisations, foreign donors, industrialists and farmers. The experiences of the developed countries where the tradition and practice of public participation has evolved to a high degree over the years have lessons for developing countries. The debate also extends to issues concerning social management and control of technology, the degree and form of public participation in decisions about technology development, deployment and regulation (Brooks, 1984, pp.39-50; Ozawa, 1991). The stakeholder approach provides a methodological tool to define technological trajectories in the context of national development.

The schema also illustrates the point that the stakeholders from their different perspectives will influence the signals that come from both within and outside the national context. As to the final output in terms of a national biotechnology programme or biotechnology policy, it is for the policy-makers to determine. However, since Ghana has a National Biosafety Committee, it may be prudent to use the Committee to determine through the process of stakeholders' consultations and conferencing. This process can be tedious and demands resources and commitment in terms of organisation and participation as shown at the National Stakeholders' Conference on Biotechnology in 1999. But the process is effective and rewarding in output in the final analysis.

This chapter has sought to emphasise the need to create a national framework to direct the course of development of biotechnology. Given the multiplicity of national development goals and sectoral objectives, there is need for such a framework. More importantly it provides motivation for the expression of available capabilities and competence. What is vital above everything however is the commitment that enables the prioritisation of biotechnology for the allocation of resources, and for the implementation, monitoring and evaluation of the programme. The commitment evolves with the biotechnology programme and therefore it is important that all stakeholders even of the seemingly antagonistic perspectives participate in the formulation of the national biotechnology programme.

CHAPTER 9

SUMMARY, THEORETICAL REFLECTIONS AND CONCLUSIONS

9.1 Introduction

This chapter is the concluding part of the thesis. It takes a bird's eye view of the analysis done in the previous chapters and draws conclusions, against the background of the defined problems and objectives. The author also takes the liberty to attempt some theoretical reflections in line with the theme of the thesis and in the context of the extensive literature available.

9.2 Highlights of Results

This thesis began on the premise that technological capacity is a strategic variable in socio-economic development. Today, the strategic value of technology has been enhanced with the growing impact of emerging technologies such as biotechnology on socio-economic activities. In the developing country context, building capacity in biotechnology has become more imperative given the potential for cross-sectoral impact and for the exploitation of natural resources. Crop agriculture in particular offers opportunities for improving production and the challenge for developing countries to build biotechnology capacity is crucial.

The study of biotechnological capacity building in Ghana is therefore aimed at making empirical contributions to the discourse on technological capacity building in the developing country context. Results of the research have shown that, the state of biotechnology in Ghana is relatively low. The assessment of biotechnology in Ghana based on the survey of biotechnology institutions in terms of their physical facilities, the information systems, the human resources and the organisational framework, showed that there are technological gaps. On the supply side of innovation, the laboratories available to scientists were not adequately equipped and in some of the biotechnology institutions there was trained expertise that did not have the tools to work with. The information systems were inadequate and the crucial connections to the global repository of knowledge (i.e. the Internet) were lacking in most of the biotechnology institutions. The institutions provided the organisational framework for their specific activities and there was also the framework for some inter-institutional collaboration. However, the larger national organisational framework that recognised biotechnology as a developmental tool and initiated policy and programmes in line with national development goals as done in Brazil, Kenya and other countries was lacking.

Indeed a comparative analysis of the experiences of other developing countries showed the extent of the gaps in the organisational framework, the regulatory regime, human resource development schemes and the overall policy environment for biotechnology development. Even in comparison with some of the African countries such as Kenya, Zimbabwe and South Africa, the gaps in these areas were substantial. The state of biotechnology in other developing countries such as Brazil, Mexico, Malaysia and Colombia also highlight the seemingly rudimentary mechanisms that Ghana needs to put in place for biotechnology development. One such important and yet basic mechanism is the formulation and implementation of a national biotechnology programme. It is however crucial to formulate such a programme through a holistic approach that ensures the participation of the critical stakeholders.

Nevertheless, there are indications of advancement in Ghana's biotechnology albeit at a pace that needs acceleration. The human resources of various biotechnology disciplines such as molecular biology, plant genetics, plant pathology and virology have potential expertise, which forms a critical base for the advancement of biotechnology. Inter-institutional collaborations particularly with institutions abroad have also enhanced biotechnological activities and are moving Ghana upward on the gradient of biotechnology. The typical example is the collaboration between the Botany Department of the University of Cape Coast and the Eastern Washington University in the U.S. where genetic transformation of cassava is going on using the particle bombardment with the gene gun with the aim of enhancing the protein content. The indicators of advancement also reflect in the establishment of biotechnology laboratories in institutions that previously did not have as well as the number of projects that were initiated. From 1990 to 1995, a total of 10 projects were initiated. From 1996 to 2000, a total of 18 projects have been initiated.

Biotechnological R&D are aimed at enhancing crop production *vis a vis* the prevailing environmental constraints - pest infestations, crop diseases, poor soil fertility and unfavourable climactic conditions. Scientists are using the tools and techniques of biotechnology to enhance crop yields, to identify and control disease vectors and improve crop resistance to all kinds of environmental stresses. The use of key biotechnology tools such as tissue culture or micropropagation, RFLP, RAPD and PCR has become routine applications in some of the institutions.

Inasmuch as the R&D focus on local crops (maize, cassava, cocoa and yam) and the problems of the production of these crops, the supply side of innovation corresponds to the needs on the demand side of innovation. However there are barriers that impede the flow of these innovations from supply to demand. There are the institutional barriers, which come as a result of certain intrinsic institutional defects e.g. lack or little outreach of the R&D institutions to the potential users of the innovations. There are the socio-economic contextual barriers relating to the profiles of the potential users who in this study are the farmers. Their level of education, low incomes, inadequate commitment to the use of scientific inputs (such as fertilisers, pesticides and weedicides) are important barriers that need to be addressed to ensure effective adoption of biotechnology innovations or products.

However, an important finding of the study is the indication of farmers' quite extensive adoption of improved seeds or planting materials. Nearly 70% of the farmers in the sample indicated that they used hybrids always in their farming. The question arises as to why the high adoption of scientifically improved seeds in contrast to other scientific inputs such as pesticides and weedicides. The answer lies squarely in the orbit of economics. With the removal of government subsidies on fertilizers, pesticides and weedicides, these inputs have been put beyond the reach of most farmers. By and large, affordability is the single most important factor in the use of these inputs. However, other factors such as the farmers' appreciation, predisposition or commitment to the use of these inputs and the exposure of the farmer to the benefits of these inputs come into play. All these are issues that need to be addressed with policy interventions.

9.3 Policy Implications

Indeed the direction of policy can be three-fold namely:

- policy to enhance biotechnology innovations (on the supply side)
- policy to facilitate use of biotechnology innovations (on the demand side)
- policy for strategic biotechnology development in relation to the national development goals.

Policy to enhance biotechnology innovations from the R&D activities in the universities and research institutions comes with improvement in the physical facilities available to them. Laboratories need to be furnished with some of the basic equipment vital for biotechnology work. Since the cost of furnishing can be very high, there is the policy option of creating centres of excellence in selected institutions. Training and re-training of expertise, creating access to vital information resources such as the Internet and encouraging networking and linkages among scientists locally and internationally will contribute to the enhancement of the national biotechnology capacity.

To stimulate and sustain demand, there are a number of policy issues that have to be considered. The first has to do with putting farmers in the position to afford biotechnology innovations of mainly improved planting materials and biofertilizers. The study of farmers in the Eastern Region has shown that while there is a high tendency to use improved planting materials, there is a marked indifference in the use of other scientific inputs such as pesticides and weedicides. Government must introduce subsidies or provide credits directly or indirectly to farmers to make their use possible.

The national vision is the attainment of middle-income status by the year 2020, which currently has been re-stated to focus on poverty alleviation. But simply re-stating the original vision is to say that Ghana will move from her present per capita income level of less than $400 to at least $1,500. In terms of human development it also means that its poverty level has to improve from its present level of about 35%, not to mention the improvement in the health and nutritional status of the people. (UNDP, 2000) A major contribution for the improvement has to come from crop production. Enhanced crop production is what will enable Ghana achieve self-sufficiency and better nutritional status leading to a healthier society. Enhanced crop production will contribute to improving on farmers' incomes or livelihoods. But this is possible with strategic interventions that seek to exploit the benefits of biotechnology. For example, Brazil identified alcohol production from sugar cane as her comparative advantage and formulated a biotechnology programme to enhance that advantage. Ghana has a range of options including the traditional cocoa, oil palm or the non-traditional crops such as pineapple, mango, banana and vegetables. A strategic policy in this regard will imply greater resource allocation to support generation of the needed biotechnology products (e.g. planting materials and biofertilizers) and supporting farmers to utilise these. Strategic policy also includes encouraging the identifiable change agents such as the extension personnel, donor agencies, private sector, the mass media and other facilitators to bring their energies to bear on the strategic goals.

9.4 Theoretical Reflections

Technological capacity building generally is a multi-faceted process. At both the institutional and national level of the supply side of innovations, the integral components of the technoware, inforware, humanware and organoware are in a dynamic interplay to produce innovations. However, the demand for such innovations is as critical as the supply and the energies that go in to facilitate the supply of innovation must go in to effectively promote demand as well. That holistic approach to technological capacity building is crucial. In this sense, capacity building proceeds on the basis of the whole being greater than the sum of the parts.

But technological capacity building is contextual. The models that have worked in the U.S., Japan, South Korea, Malaysia or Mexico may not necessarily work in Ghana. Ghana has her own development vision and needs, has her own comparative or competitive advantage(s) and her socio-economic situation is a fingerprint of a kind. Besides, the nature and type of technologies define the trajectories of technological capacity building. Biotechnology is a technology of peculiarities that dictate the approach to its capacity building process. For Ghana, that approach should be holistic but should not necessarily be too general to the extent that, focus and strategy become effaced. The issue of resource limitation at all levels of the economy is one of the countervailing variables in the efforts to build biotechnological capacity. There is therefore the need to adopt appropriate policy options that make maximum utilisation of available resources and address the complexity of issues that arise due to the peculiarity of biotechnology.

9.5 Conclusion

This thesis reiterates the point that capacity building for biotechnology application and development is best done within a policy framework that takes account of the socio-economic context. In the absence of a definitive framework, the national biotechnology capacity is characterised as follows:

- Ghana's capacity in biotechnology is low but it is advancing and the pace of advancement needs to be enhanced.
- Tissue culture, molecular biology techniques such as DNA fingerprinting, use of ELISA, RFLP, PCR and transfer and replication of genes have become established routine tools in the work of some of the local scientists. However, the impact of these applications in spite of the potential for the future may be minor, if not non-existent. This is due to the relatively poor capacity of users to adopt scientific inputs due to factors, which include inadequate incomes and poor linkages with the scientific communities.
- Biotechnology applications relate directly to national goals in the efforts to address the major constraints of crop diseases, pest infestations, low yields and vulnerability to stress. Overcoming these constraints is essential to the national strategy of achieving food security, enhancing productivity on the farms and poverty reduction.
- Given the predisposition of farmers to adopt scientific inputs in their farming activities, there is demand for biotechnology products. However, the demand needs

nurturing with appropriate policy interventions such as provision of credits or subsidies and an enhanced extension service.

- To achieve the vision of middle-income status and alleviate poverty as current development strategies envisage, Ghana needs to create a biotechnology capacity that generates her own specific biotechnology innovations for crop farming and also the capacity to use these innovations.
- The best practice given the lessons from countries advancing in the application and development of biotechnology illustrates that Ghana needs to make precise commitments to biotechnology utilisation as a strategic technology. Such commitment must not only manifest in policy statements but must be evident in the allocation of resources, the definition of the institutional and regulatory or legislative framework, provision of incentive structures for private sector participation, the support for the information system and the mechanisms for human resource development. The approach to formulating a national biotechnology programme should be holistic and take into account the international and internal factors that influence biotechnology capacity development. It should take into account issues such as proprietary rights over the technology, impact on farmers' interests and biosafety. The holistic approach to capacity building reiterates the concept that technological capacity is a whole, which is greater than the sum of its parts.

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APPENDIX 1

QUESTIONNAIRE: DEMAND FOR BIOTECHNOLOGY PRODUCTS FOR CROP PRODUCTION - FARMERS' RESPONSES

Please, this questionnaire is ONLY for purposes of research in connection with a post-graduate academic work at the Centre for Development Studies of the University of Cape Coast. Respondents are therefore guaranteed absolute confidentiality.

1. Personal information of farmer or farm owner

1.1 Name of farmer (Surname first)…………………………………………..…

1.2 Address (including telephone, if any) ……………………………….………

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…………………………………………………

1.3 Age……………………………………………………………………………

1.4 Nationalitity…………………………………………………………………

1.5 Sex (please tick) Male……………Female……………………..

1.6 Educational Qualification……………………………………………………

1.7 How many years have you been engaged in farming…………………………

2. Farm data

2.1 Type of farm (tick) (a) mechanised (b)semi-mechanised (c) subsistence

2.2 When was farm established (year)?

2.3 Type of crop, total acreage,

Crop	Acreage
1. 2 3 4 5.	
Total	

2.4 Farm workers categories and numbers

Level of schooling	Number of workers
1. Ph.D. 2. Master's degree 3. B.Sc./ B.A. 4. Diploma 5. Advanced level 6. Ordinary level 7. Basic 8. No schooling	
Total workers population	

2.5 What percentage of crop produced is exported, sold on the local market or consumed at home?

(a) Name of crop: ......% exported.......% sold locally.......% consumed.........

(b) Name of crop: ......% exported.......% sold locally.......% consumed.........

(c) Name of crop: ......% exported.......% sold locally.......% consumed.........

(d) Name of crop: ....% exported.......% sold locally.......% consumed.......

2.6 Are some seeds saved from harvest for the next planting season? (Please tick)

Yes.... No......

2.7 What is the annual net profit from the farm? (Mark with asterisks if only estimates availbable)………………………………………..

3. Key problems in the production of stated crop (tick and rank in order of importance):

3.1 Please provide information on the key problems faced in the production of the top three crops grown on the farm and rank in order of importance with rank 1 being the most important and rank 10 the least.

(a) Name of crop……………………………………………………………………...

Key problem	Tick if yes	Give examples where possible	Rank
1. Crop diseases 2. Crop pests 3. Low yields 4. Susceptibility to drought 5. Susceptibility to flooding 6. Low nutritional content 7. Degrades soil 8. Poor production in low fertility soils 9. Poor post harvest storage 10. Vulnerability to high temperatures			

b) Name of crop……………………………………………………………………...

Key problem	Tick if yes	Give examples where possible	Rank
1. Crop diseases 2. Crop pests 3. Low yields 4. Susceptibility to drought 5. Susceptibility to flooding 6. Low nutritional content 7. Degrades soil 8. Poor production in low fertility soils 9. Poor post harvest storage 10. Vulnerability to high temperatures			

c) Name of crop.................................. ....

Key problem	Tick if yes	Give examples where possible	Rank
1. Crop diseases 2. Crop pests 3. Low yields 4. Susceptibility to drought 5. Susceptibility to flooding 6. Low nutritional content 7. Degrades soil 8. Poor production in low fertility soils 9. Poor post harvest storage 10. Vulnerability to high temperatures			

4. Agricultural inputs

4.1 Do you use any kind of agricultural inputs?

(a) Yes (b) No

4.2 Indicate how often you use the following inputs by ticking as appropriate

Input	always	sometimes	occasionally	rarely	Not at all
Fertilizers					
Weedicides					
Pesticides					
Hybrids					

5. What factors make you decide to use any of the above inputs?

5.1 Fertilizers

i) Increase in production when used

ii) Better quality of harvest

iii) Makes farming easy (reduces drudgery)

iv) Reduces cost of production

6. Suggest ways in which the available agricultural inputs need improvement

....

....

7. Where do you get information on agricultural innovations and new inputs for your farming activities. (Please rank in order of importance)

- Agricultural extension officers of the Ministry of Food and Agriculture
- Scientific officers of the research institutes (of the Council for Scientific and Industrial Research)
- Research officers or lecturers of the universities
- Mass media (i.e. radio, newspapers and television
- Farmers and farmers' associations
- Private sector distributors of agricultural inputs
- Internet
- Others (please specify)

8. How do you assess the importance of the following mass media in providing you with information? (Please rank in order of importance, with 1 being the most important)

- Television
- Radio
- Newspaper
- Subject matter publications (bulletins, newsletters and magazines)

9.Suggest ways of ensuring effective dissemination of biotechnology products

………

………

………

…………………………………………………………

10.Linkages with Scientific Institutions

10.1 Have you ever consulted any of the scientific institutions (research institutes or universities) in connection with your farming activities before? (please tick)

Never….A few times….Quite often……Often……

10.2 If you have ever consulted, how do you assess the ability of local scientists to address your problems? (Please tick) Very good…..Good….Average….Poor…Don't know….

10.3.Give examples of fruitful consultation with any of the local scientists

………

……………………………………………………………………………

11. Government Policy

11.1 Do you consider government policies adequate in promoting the use of innovations? (Please tick as appropriate)

Adequate…..Quite adequate…..Not adequate…..Don't know…..

v) Environmental friendliness

5.2 Weedicides

i) Increase in production when used

ii) Better quality of harvest

iii) Makes farming easy (reduces drudgery)

iv) Reduces cost of production

v) Environmental friendliness

5.3 Pesticides

i) Increase in production when used

ii) Better quality of harvest

iii) Makes farming easy (reduces drudgery)

iv) Reduces cost of production

v) Environmental friendliness

5.4 Improved/ hybrid seeds

i) Increase in production when used

ii) Better quality of harvest

iii) Makes farming easy (reduces drudgery)

iv) Reduces cost of production

v) Environmental friendliness

11.2 What suggestions will you make to improve government policy to facilitate the adoption and use of innovations?

……………………………………………………………………………………

……………………………………………………………………………………

APPENDIX 2

INTERVIEW GUIDES

A. Interview Guides for Scientists

1. Personal information (name and address)
2. What research project(s) are you currently working on?
3. What research projects have you worked on in the past?
4. What is the duration of the projects and have there been any extensions?
5. What stimulated the project? (e.g. research for further studies, foreign collaboration, personal interest, etc.)
6. Who fund(s) the project? Kindly provide details about the levels of funding by the funding parties.
7. What biotechnology techniques do you utilise?
8. What equipment and facilities are dedicated to or shared by your project or department?
9. What is the potential for applying the research results? Are there specific local problems the research project aims at solving?
10. Who receives the outputs of your project?
11. What are the barriers in implementing the research project?
12. What collaborative arrangement(s) do you have with other local and foreign organisations?
13. How many people are working on your research projects? Indicate their qualifications and specialisations.
14. What problems should the government and the respective agencies address in order to facilitate the development of biotechnology capacity in Ghana?

15. In your opinion, who else needs to be interviewed in my research?

B. Interview Guide - Policy Makers/ Government Officials

1. Personal information (e.g. name and address)
2. What are your organisation's functions and objectives?
3. What are your specific responsibilities?
4. What policy decisions are you involved in?
5. How do your policies/ regulations, etc. relate to the utilisation, development and management of biotechnology?
6. Is there any institutionalised mechanism for policy research in your organisation?
7. What type of expertise do you have in your department?
8. What is your opinion of biotechnology application in crop agriculture in Ghana?
9. How do you envision the development of biotechnology in Ghana in future in the context of the national development agenda?
10. What are the issues that Ghana needs to address from your point of view in order to facilitate the advancement of biotechnology in Ghana?
11. Do you have any collaboration with any local or foreign organisations and what is the nature of these collaborations?
12. What are your concluding thoughts on Ghana's biotechnology development?

C. Interview Guide - S&T Information System

1. Personal information (name and address)
2. What is your assessment of the information system available at INSTI - how modern, how efficient?

3. Do you know of any computerised system or database similar to TEEAL and GHAGRI in other institutions in Ghana?
4. From the GAINSNEWS it is apparent that some of the key stakeholders of your information system such as farmers and agricultural extension officers do not use your QAS (and your information system). How come? Content not relevant or simply more skewed to the researchers/ academics?
5. Any particular efforts aimed at enhancing usage of the TEEAL and GHAGRI and INSTI's information system on the part of farmers and other agricultural workers?

APPENDIX 3

DETAILED COST OF STANDARD TISSUE CULTURE LABORATORY

Equipment and Supplies	Cost in Cedis ('000)	Cost in US dollars*
A. Key Equipment and Supplies		
Peristaltic dispenser (vacuum pump)	9,700.00	1,385.71
Laminar flow hood	50,000.00	7,142.86
Growth cabinet (220-240v)	20,000.00	2,857.14
3-tiered gyrotary shaker(250ml)	35,000.00	5,000.00
3-tiered gyrotary shaker (500ml)	40,000.00	5,714.29
Magenta vessels (50)	300.00	42.86
Double distilled waterstill (240v)	20,000.00	2,857.14
Bench top centrifuge	6,000.00	857.14
Micro centrifuge	8,000.00	1,142.86
Sterilisation equipment (glass/hot beads)	2,500.00	357.14
Stereo Microscope (512) and accessories	15,000.00	2,142.86
Refrigerator	7,000.00	1,000.00
Microwave oven (electrical oven)	3,000.00	428.57
Pipette washer and dryer	8,740.00	1,248.57
Surgical blades (one packet)	70.00	10.00
Pre filter for flow hood	110.00	15.71
Autoclave	60,000.00	8,571.43
Magnetic stirrer hot plate	2,800.00	400.00
pH meter (electrode stand and arm)	9,000.00	1,285.71
Jiffy peats pellets (1000)	1,000.00	142.86
sealing machine	300.00	42.86
sprayer (spraying bottle)	20.00	2.86
trolley	1,400.00	200.00
Petri dishes (500)	1,460.00	208.57
500 Hardening trays (Watson Containers)	1,500.00	214.28
Thermohydrographs	16,000.00	2,285.71
Sub-total	309,440.00	44,205.71
B. Other Equipment		
Computer and accessories	15,000.00	2,142.86
UPS equipment	5,000.00	714.28
Generator*	50,000.00	7,142.86
Air conditioners	6,000.00	857.14
Sub-total	76,000.00	10,857.14

C. Farm Facilities		
Farmland (1 acre)*	10,000.00	1,428.57
Irrigation system *	4,000.00	571.43
Nursery (including screenhouse)*	20,000.00	2,857.14
Sub-total	34,000.00	4,857.14
Total	419,440.00	59,920.00

Source: Information Supplied by courtesy of Dr. Harry Amoatey, Head of the Tissue Culture Laboratory of BNARI based on some purchases and sales brochures.
*The exchange rate used for the year 2001 was 7,000 cedis to US$1.00

APPENDIX 4

MISCELLANEOUS DATA

A. Production of Selected Food Crops ('000mt)

Crop	1992	1993	1994	1995	1996	1997	1998	1999	2000
Cassava	5,662	5,973	6,025	6,611	7,111	7,000	7,172	7,845	8,107
Yam	2,331	2,720	1,700	2,126	2,275	2,408	2,703	3,249	3,363
Plantain	1,082	1,322	1,475	1,637	1,823	1,818	1,913	2,046	1,932
Cocoyam	1,202	1,236	1,148	1,408	1,552	1,530	1,577	1,707	1,625
Maize	731	961	940	1,034	1,008	996	1,015	1,015	1,013
Sorghum	259	328	324	360	353	333	355	302	280
Millet	133	198	168	209	193	144	162	160	169
Paddy Rice	132	157	162	221	216	197	281	210	249

Source: MOFA, 2001.

B. Land Use in Ghana

	Hectares	Percentage
Total land area	23,853,900	100
Agricultural Land Area	13,628,179	57.1
Total area under cultivation (2000)	5,808,600	24.4
Total area under irrigation (2000)	11,000	0.05
Area under inland waters	1,100,000	4.6
Others	9,125,721	38.3

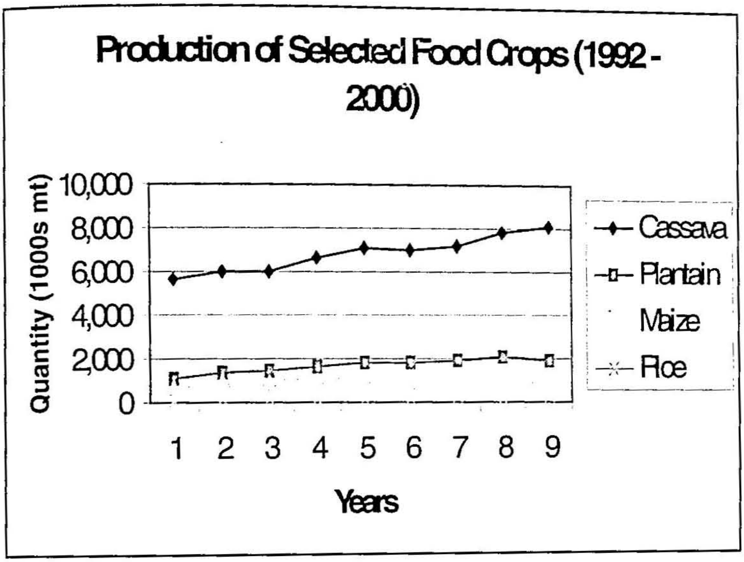
Source: MOFA, 2001.

C. Performance of the Non-Traditional Export Sector: 1994-1999

Item	1994	1995	1996	1997	1998	1999
Total value of NTEs ($)	119.3	159.7	276.2	329.1	401.7	404.4
Value of Agric.NTEs ($)	39.2	27.4	50.3	57.4	77.8	84.5
% of agric. NTE of total	32.9	17.2	18.2	17.4	19.37	20.9

Source: Ghana Export Promotion Council, 2000

D.



Source: Based on MOFA, 2001, p.9

E. **Farmer Yields of Selected Crops Compared to Achievable Yields**

Crop	Yields (Mt/Ha)	Achievable Yields, (Mt/Ha)
Cassava	11.8	28.0
Plantain	7.8	10.0
Yam	12.3	20.0
Cocoyam	7.0	8.0
Maize	1.5	5.0
Rice	2.0	3.0
Cowpea	0.75	2.0
Millet	0.9	2.0
Sorghum	1.1	2.0
Cocoa	0.39	1.0
Tomato	7.5	15
Garden eggs	8	15

Source: MOFA, 2001, p.11

APPENDIX 5

LIST OF INTERVIEWEES

No.	Institutions/ Organisations	Interviewee	Address
1 2 3 4	BNARI	Prof. George Klu Dr. Harry Amoatey Mr. David Bansah Mr. Charles Gbedemah	BNARI, Ghana Atomic Energy Commission, Kwabenya
5	Crops Science Dept,U.G.	Dr. S.K. Offei	P.O. Box 44, University of Ghana, Legon
6	Botany Dept, U.G.	Prof. Elizabeth Acheampong	University of Ghana, Legon
7	Biochemistry Dept.	Dr. Yaa D. Osei	University of Ghana
8 9	Botany Dept., U.C.C.	Mr. Isaac Galyuon Mr. G. Otwe	University of Cape Coast
10	Crops Science Dept., KNUST	Rev. Prof. Osei Safo-Katanka	KNUST, Kumasi
11 12	Dept. of Biological Sciences, KNUST	Dr. Robert Abaidoo Dr. Frempong	KNUST, Kumasi.
13	Biochemistry Dept., KNUST	Prof. Mrs. Victoria Dzogbefia	KNUST, Kumasi
14 15 16 17 18	Crops Research Institute	Dr. K. Hemeng Dr. Felix Nyarko Dr. Hans Dapaah Dr. Ernest Otoo Dr. N. Lamptey	Crops Research Institute, P.O. Box 3785, Kumasi
19	Soil Research Institute	Mr. J. Fenning	Soil Research Institute, Kumasi
20 21	Forest Research Institute of Ghana	Dr. J. Cobbinah Mrs. Theresa Peprah	FORIG, Ghana
22 23 24	SARI	Dr. K.O. Maafo Mr. Meschark Abdulai Dr. K. Nutsugah	SARI, P.O. Box 52, Tamale
25	PGRC	Dr. S.O. Bennett-Lartey	Plant Genetic Resources Research Centre, P.O. Box 7, Bunso
26	Dept of Biological Science, U.D.S.	Mr. Richard L. Glover	University of Development Studies, P.O. Box 1350, Tamale
27 28	Cocoa Research Institute	Dr. Yaw Adu-Ampomah Dr. Sackey	CRIG, P.O. Box 8, New Tafo Akim.
29 30	Coconut Project	Dr. Sylvester Dery Mr. F. Arthur	Coconut Project, P.O. Box 245, Sekondi

31	OPRI	Dr. J.B. Wonkyi-Appiah	Oil Palm Research Institute, P. O. Box 74, Kusi, Kade
32	INSTI	Mr. Entsuah-Mensah	INSTI, C.S.I.R., P.O. Box M32, Accra
33 34	C.S.I.R.	Prof. W.S. Alhassan Prof. A. Oteng-Yeboah	C.S.I.R., P.O. Box M32, Accra
35	Food and Drugs Board	Mr. K. Owusu-Sekyere	Food and Drugs Board, P.O. Box CT 2783, Accra
36 37 38	MEST	Dr. Farouk Braimah Mr. E.D. Barnes Dr. Rexford Osei	MEST, P.O. Box 232, Ministries, Accra
39	MOFA	Dr. S.K. Dapaah	MOFA, P.O. Box M37, Accra
40	PPRSD	Mr. Paa Kwesi Entsie	MOFA, P.O. Box M37, Accra.