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Harnessing microbial resources for increased agricultural productivity and improved livelihoods

D. K. Byarugaba

Department of veterinary Microbiology and Parasitology, Faculty of Veterinary Medicine, Makerere University, P.O. Box 7062, Kampala, Uganda,

Abstract

Fifty percent of the living biomass on the planet is said to be microbial and microorganisms provide a major source of genetic information to solve many problems in agriculture, industry, plant, animal and human health and several other biotechnological applications. The vast majority (95%) of the microbial diversity however, is yet to be discovered, and most of this unexplored megadiversity is found in tropical regions with a wide range of ecological habitats. Uganda has a wide range of ecological habitats with an abundance of novel taxa of culturable and unculturable microorganisms of great potential value. These organisms are involved in nutrient recycling (e.g. breaking down complex plant and animal remains), beneficial mutualistic relationships (e.g. nitrogen fixation, animal digestion, *mycorrhiza*), and production of atmospheric oxygen. They are also important pathogens of pests and disease causing organisms; hence, may be harnessed by man for the biological control of pests in integrated pest management programmes. Their other uses include production of natural products (e.g. valuable drugs, enzymes, and metabolites) for pharmaceutical, food and other applications, composting, bioremediation and detoxification of wastes. They play a major role in soil fertility and plant and animal health and are employed in diagnostics, efficacy testing of drugs, biocides, vaccine production and disinfectants or as reference strains. Uganda currently lacks mechanisms for integrated management and utilization of these microbial resources. This paper reviews the potential and strategies for harnessing microbial resources in Uganda to provide solutions to natural resource depletion, environmental, agricultural, food, forestry and public health concerns and contributions towards poverty eradication and improved livelihoods of the people.

Key words*:* Agriculture, development, microbial diversity, poverty alleviation

Introduction

Microorganisms are microscopic organisms, not normally visible to the naked eye. They include bacteria, fungi, algae, protists, and viruses. They are an essential component of biological diversity, and serve an important role in the maintenance and sustainability of ecosystems. Of the living biomass on the earth, fifty percent is made up of microorganisms. Very little is known about microbial species, their functional diversity and their influence on sustainable ecosystems the world over, more so in developing countries (Hawksworth, 1992). The first microorganisms evolved over 3.8 billion years ago and consequently exhibit the greatest breadth of genetic and metabolic diversity on the planet, far greater than that of the plants and animals combined and occur in all ecosystems (Fig 1.) (Staley *et al.*, 1997). Recent advances in molecular methods have shown that the species' diversity in most terrestrial and aquatic environments is far greater than expected (Hugenholtz and Pace, 1996) and the vast majority (>95%) remain to be discovered (Amann *et al*., 1995). Agriculture is the mainstay for Uganda's economy contributing about 40% of the total GDP and 55% of the total exports. This sector employs over 80% of the population. With Uganda's well-known richness in biodiversity, both terrestrial and aquatic that harbor enormous microbial resources, this would be a strategic advantage to exploit these resources for increased agriculture to improve peoples' livelihoods. The significance of agriculture in reducing poverty is confirmed by several data sets that indicate that 10 % growth in agricultural GDP per capita leads to a 16% increase in the per capita incomes of the lowest fifth of the population (World Bank, 2004). It is known that losses in agriculture are related to loss in soil fertility and diseases and pests. Adoption of modern agricultural technologies using the rapidly advancing biotechnology, which incorporate robotics, metabolomic, proteomic and genomic technologies coupled with diversification of crop and animal production systems and efficient management of natural resources is vital in this process. Herein lies the potential of using the enormous resource of microorganisms available locally to provide solutions to increase crop yields and quality, pest/disease control, and protection of harvested crops besides the other

uses in agriculture, livestock, pharmaceuticals, conservation, industrial/chemical, bioremediation and water treatment and prevention of environmental degradation, thus improve peoples livelihoods.

The status of microbial resource utilization in Uganda

Previous studies have presented a comprehensive overview of the ecosystem and species diversity in Uganda, covering mainly, mosses, ferns, higher plants, protozoa, rotifers, platyhelminthes, nematodes, annelids, molluscs, insects, crustaceans, spiders and scorpions, ticks and mites, fishes, amphibians, reptiles, birds, and mammals but very little of the microorganisms (NBU, 1992; NBDB, 2000; NBDB, 2002). They have also examined the ecological status of Uganda's plants (domesticated, wild, and edible) and animals, both in the wild (including invertebrates, fishes, herpetofauna, birds, mammals) and domesticated. The future of protection of biodiversity and including microbial diversity in Uganda will rely heavily on protected areas of the wild given the population pressures on other unprotected areas. Their management is therefore of paramount importance although much diversity also exists in non-protected areas and due consideration must be given to these areas too.

Biodiversity conservation is not limited to organisms and habitats but there is also due concerns for the gene pools of the respective populations (Fig. 1 Box 1). Primitive wild type species are immense repositories and reservoirs of gene assemblies of adaptive value. Loss of diversity undermines sustainability of the biological systems. There are still many gaps within the current knowledge that need plugging through inventories, revisions of taxa, describing all the known families, genera and species in greater detail than is currently available and doing more research on the yet to be identified and classified species especially of microbial diversity and exploitation for potential benefits. The current status of microbial resource utilization and conservation has been recently reviewed (Byarugaba, 2004). Table 1 shows some aspects of utilization of microorganisms in Uganda Agriculture.

Threats to biological resources

The decline in 'megadiversity' regions and 'hot spots' of endemic flora, fauna, and microorganisms has focused scientific and commercial attention on the remaining regions, particularly in the tropics although, extreme environments such as acidic, thermophilic, hypersaline, and arid regions, are equally important 'hot spots' of microbial 'megadiversity'. These are habitats of microorganisms, which have the genetic and physiological capacity to survive and grow under harsh or extreme conditions through which they have evolved while shaping the environment. Microorganisms including the prokaryotes (bacteria and archaea), the eukaryotes (fungi including lichen-forming species, slime moulds, and yeasts; algae and protozoa), and viruses occupy important niches in all ecosystems, and are responsible for much of the recycling of the elements in nature (e.g. the decomposition and recycling of organic matter in forest ecosystems), and are important components of the food chain. The loss of Uganda's biodiversity has been estimated to be about 1% per annum and this loss also includes the microbial diversity associated with it (NBDB, 2002). The greatest loss of biodiversity ever recorded on earth is said to be on L. Victoria (Witte *et al.*, 1999).

The potential benefits of microbial resources

Microorganisms are an essential component of biological diversity, without which there can be no sustainable ecosystems. They are a major resource for biotechnology, which is recognized universally as one of the key enabling technologies for the 21st century (Bull *et al.*, 1992). Microorganisms often have unique functions in the biogeochemical cycles (e.g. nitrogen fixation, nitrification, denitrification, chemolithotrophic, carbon dioxide fixation, methane formation, and sulphate reduction), in soil formation, in climate regulation, and influence atmospheric composition [including greenhouse gases (Nisbet, 1992). Microbes have a profound impact on every facet of human life and everything around us. Pathogens harm us, yet other microbes protect us. Some microbes are pivotal in the growth of food crops, but others can kill the plants or spoil the produce. Bacteria and fungi eliminate the wastes produced in the environment, but also degrade things we would rather preserve.

Indigenous biological resources and their diversity provide a wide range of direct and indirect economic benefits. Exploitation of microbial diversity in particular would be very useful in many areas including those listed in box 1.The quantified value for the direct economic benefits of Uganda's biodiversity has been estimated to be more than Ug Shs 823 billion a year from the forests, woodland resources, tourism from forest reserves, non-forest plant resources, wildlife resources, inland water resources, plus indirect benefits such as erosion control, water retention, water purification and carbon sequestration (NBSAP, 2000). This figure is only a small proportion of the value of biological resource value, and the proportion played by microorganisms in this is not estimated. Uganda's potential is therefore enormous and could propel the country out of poverty if accordingly harnessed. Elsewhere in the world there are over 120 products currently being marketed around the world including nine blockbuster drugs originating from biologicals (Biopharmaceuticals Report http://www.researchandmarkets.com/reports/39083). The global market is currently valued at US$41 billion growing at a rate of 21% over the past five years. It is considered that the total pharmaceutical market could easily reach US$100 billion by the end of the decade. Table 2 shows the value of some of the products from microorganisms.

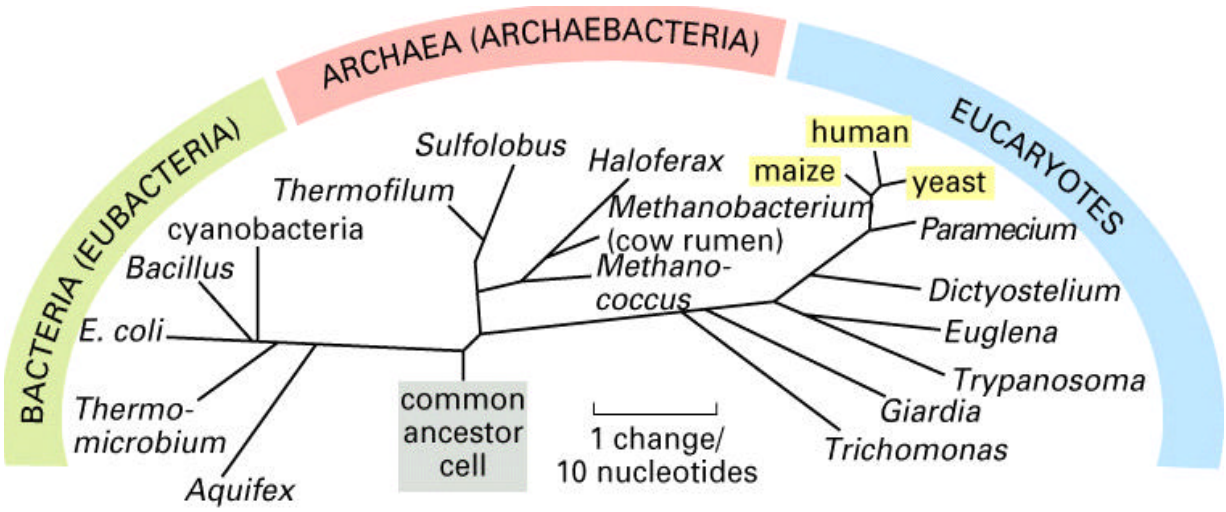

Fig 1. The phylogenetic relationship of microorganisms with other plant and animals

Table 1. Examples of current utilization of microorganisms in Ugandan Agriculture and Food processing

Institution	Organism (s)	Purpose
Forest Resources Research Institute (FORRI)	Mycorrhiza spp Rhizobia spp Pathogens	Improve tree health Improve soil fertility Design control
Kawanda Agricultural Research Institute (KARI)	*Beauveria bassiana* *Bacillus thuriengensis* Pathogens	Biocontrol of pests Biocontrol of pests Design control
Food Science and Technology Institute (FOSRI)	Pathogens Fermentative agents	Food safety Food processing
Namulonge Agricultural and Animal Production Research Institute (NAARI)	*Metarhizium* spp *Bacillus thuriengensis* *Hirsutella spp* Pathogens	Termite control Waterhyacinth control Cassava green mite Design control
Fisheries Resources Research Institure (FIRRI)	Cyanobacteria Other organisms	Monitor toxicity Wastewater treatment
Livestock Health Research Institute (LIRI)	Animal pathogens	Diagnosis and control
Faculty of Agriculture (MUK)	Plant pathogens Soil organisms	Diagnosis and control Improve soil fertility
Faculty of Veterinary Medicine	Animal Pathogens	Diagnosis and control
Faculty of Science	Environmental organisms Pathogens	Environmental management Design Control
Uganda Industrial Research Institute (UIRI)	Fermentative organisms	Food processing

Table 2. Examples of revenue from microbial resources

Product	Revenue (US $)
Cyclosprorin (Fungal derivative)	1.5 billion
Clarothomycin (fungal derived)	1.6 billion
Amoxycillin (fungal derived)	1.8 billion
Industrial detergents	0.9 billion
Bioremediation of soil in EU	60 billion
Total current drug market value (derived from microorganisms)	41 billion

- Combating animal and plant disease pathogens and pests that limit agricultural production on which the country's economy depends and on which 80% of population is dependent
- Improved capacity to sustain soil fertility and water quality, and the environment
- The discovery of microoganisms for exploitation in biotechnological processes for new antimicrobial and therapeutic agents, probiotics, novel fine chemicals, enzymes and polymers for use in industrial and scientific applications through joint academic and industrial ventures
- Increasing crop yields and quality in the region by exploiting organisms such as *Rhizobium*, , and nitrogen fixing bacteria
- Waste management and bioremediation of polluted environments, and bioleaching and recovery of minerals,
- Preparedness against exotic and emerging pathogens of humans, animals and plants
- A better understanding of the role and function of microbial communities in various environments and ecosystems to enable sustainable utilisation of those resources
- Understanding the ecology of miroorganisms in order to avoid environmental degradation, animal and plant extinction, and perturbations on ecosystems
- Improving disease and pest diagnosis and control in humans.
- Provision of general microbiological services including enumeration in foods or water, daignostic, microbial resistanace testing, identification etc.
- Improving biocontrol of weeds and ecosystem management such as the Water Hyacinth on L. Victoria
- Improving the safety of foods and beverages by developing detoxification measures against foodborne intoxications and infections
- Biodiversity conservation for cultral and social values
- Improved forest coverage by improving afforestation of arid areas by soil improvement with *Mycorrhiza* for example
- Application of microorganisms in biotechnology in industry to improve income and enhance people's livelihoods

Box 1. Potential areas for utilisation of microbial resources in Uganda

The global potential is thus enormous and Uganda could partake of this global exploitation and derive substantial benefits from her unexploited microbial and other genetic resources. The Iwokrama programme demonstrates an example that tried to demonstrate how tropical forest biodiversity may be conserved and sustainably utilized for ecological, social and economic benefits. 1 in 3 microorganisms isolated and tested demonstrated activities, particularly anti-insect, anti-fungal and anti-bacterial activities.

Problems associated with exploitation of microbial diversity

Biotechnology discovery is not only difficult but also very expensive. It is estimated that there is 1 chance in 250,000 for an unknown chemical reaching the market. Not only is the chance of getting a product to market low the time frame can be long of average 10-15 years before rewards are seen. The pharmaceutical industry reports that it costs them a minimum of Us$ 500 million to bring a single drug to the market. Chances of active molecule discovery are enhanced when metabolism can be manipulated. Linking this to the knowledge of ecosystems and targeted isolation programmes, can give access to the most promising organisms. Frequently, valuable collections of isolates are discarded or neglected on the retirement of a researcher, because of changes in institutional priorities.

Strategies for harnessing the potential of microbial resources in Uganda

In recognition of the continued depletion of biological resources and the need for conservation of the world's biodiversity (including microorganisms), the Convention on Biological Diversity (CBD) was agreed at the Earth Summit in Rio de Janeiro in 1992. The Convention came into force in December 1993 and has now been ratified by more than 180 countries. Uganda is a signatory and has a commitment to the conservation of her rich biological resources including microbial resources. This requires putting mechanism in place to achieve the objective.

Bioprospecting into microbial diversity in Uganda

Bioprospecting geared towards discovering novel properties and products from living organisms has been intensive worldwide. The relatively new disciplines of genomics, proteomics and metabolomics and associated microarray technologies have enhanced speed and throughput. Concomitant to this development is the discovery of new microorganisms. It is essential that representatives of these and other useful organisms be maintained for future use. If a strain is lost, recovery of that strain or even the same species from its natural environment can be difficult or impossible. Research is therefore critically required to investigate the diversity and taxonomy of Ugandan microorganisms as has been carried out for the flora and fauna. A thorough study will lead to a comprehensive description of microorganisms and their ecology. The task of conservation necessitates the setting of priorities (e.g useful organisms) in order to make inroads in a logical way. Although it is difficult to predict which may be useful in the future, the initial aim should concentrate initial effort on microorganisms harnessed by humankind in several areas, including the use and production of food, those important in medicine, agriculture, forestry and industry.

Setting up culture collections of microbial resources

Microbial resource collections carry out the conservation function. Access to cultures of microorganisms, cell lines, and genetic material, is an essential requirement for the conduct of microbiology and related disciplines. In developing countries, microbiologists working in industry, quality assurance, human, animal, and plant health, research, and education are disadvantaged compared with those in most developed countries. Uganda has no adequately resourced national collections of microorganisms, and it is difficult to easily access information on microbial resources (including standard reference and type cultures and conserved Ugandan microbial diversity). Microbiologists are also disadvantaged by delays in obtaining cultures from overseas caused by stringent quarantine restrictions and therefore require extensive reference collections in Uganda to overcome these difficulties. Human activity can also have a devastating effect on the environment and habitat destruction will eventually destroy a proportion of the microbial diversity. The *ex situ* conservation of microorganisms from the environment can ensure their availability for future use if their natural environment is destroyed. It is therefore imperative that isolates are adequately preserved to maintain their integrity and for future use in screening, genetic improvement, characterization, and the production of desirable end-products. Long term preservation of microorganisms is a major role of microbial gene banks.

A national culture collection of microbial resources would maintain and preserve representative cultures derived from bio-prospecting programmes to meet current and future needs. Ex-situ conservation of cultures would encompass the representative cultures of species, metabolic, genetic, epidemiological, and evolutionary diversity. National infrastructure funding and legislative protection should be in place to ensure the long-term continuity and security of these microbial diversity collections. The collections provide a range of services such as the supply of cultures, and will also act as reference centers for the identification of isolates. The collections also act as repositories of gene clones required for bioscience.

Information Access

Timely, relevant and good quality data and information is very essential for effective conservation planning. Such data enable rational decisions to be made concerning conservation programmes of biodiversity. In Uganda like many other developing countries, biodiversity information is scattered in different departments within government, research institutions and universities. This information is kept in varying forms and contains many gaps depending on the purpose for creation of such databases. Such gaps in spatial and temporal distribution of species are usually inadequate for planning conservation strategies.

Electronic access to information on the location of microbial cultures in Uganda is essential for the supply of cultures for research, education, standard methods, human, animal and plant pathology, and industrial applications, but also for an up to date inventory of the biogeographic distribution of Ugandan microbial and genetic resources. A microbial information resources centre should be established to maintain a database on the microbial resources in the country and provide linkages to users, and stakeholders as well as international partners. Standardized web-based software should be designed for the management of culture collection databases and resources, the retrieval and analysis of data, and the printing and publication of catalogues. Large collections may prefer to maintain their own distributed databases using the standard software, while small culture collections may decide to accession their data directly on the main network via the Internet. Information searches can automatically include all databases in the centre. Each collection can have access to the software programs via the internet to manage the data in their own collections. Microbiology laboratories and individual microbiologists should also be able to use the software to maintain databases of their isolates, representatives of which will be accessioned into the national collection at the completion of the research. The center should also be able to provide a single point of entry and a gateway to other national and international databases of information on microbial and biological diversity and culture collection databases.

Policy, legislative and regulatory framework

An appropriate legal framework and deliberate policy for the exploitation and sustainable utilization of microbial resources is very crucial. This will set the guidelines and action plans towards the realization of the overall goal of harnessing microbial resources for improving the livelihoods of the people. Uganda is signatory to the Convention on Biological Diversity (CBD) (UNEP, 1992) and therefore has the obligation for the conservation and sustainable utilisation of her genetic resources The CBD gives a comprehensive framework for conserving sustainable utilisation of biological diversity to provide the solutions to natural resource depletion, environmental, agricultural, food, forestry and public health concerns which should help to alleviate poverty and boost national economies by utilising the strategic advantage that Uganda has.

Although, Uganda has a well-developed legal and institutional framework touching on biodiversity issues (Byarugaba, 2004), there are no action plans spelt out for conservation and sustainable exploitation of the microbial resources in the draft NBSAP (The draft National Biodiversity Strategy and Action Plan, 2000). Specific action plans therefore will be required and this also entails committing financial resources, to meet the immediate identified national needs and goals. Implementation of CBD objectives such as the "fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding" needs to be done as well as addressing intellectual property rights (IPR) and safeguarding the nation against potential risks that may be posed by living modified organisms (LMOs) resulting from modern biotechnology. Initial steps although have been done (Draft regulations on to Access to Biological Resources and Benefit Sharingin Uganda,) much more is needed to enforce these laws. The Cartagena Protocol to which Uganda is signatory (UNEP, 1995) aims to contribute to ensuring an adequate level of protection in the field of the safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements.

Creation of partnerships and networks

Identification of potential stakeholders and partners and establishing networks is one of the most significant ways of pulling together the required scientific, technical and financial resources to achieve the goal of harnessing microbial resources for improvement of peoples' livelihoods. Several national regional and international initiatives such as the East African Community (EAC), New Partnership for African Development (NEPAD), ASARECA, Africa Bioscience Network, BIOEARN and many others have created an enabling environment for networking through a number of ways including mobilising and making available technical expertise to support local expertise through appropriate sub-regional and regional platforms for R&D and to ensure efficient and effective utilisation of meager resources for achieving common goals. The East African Community (EAC) for example has identified agriculture and animal husbandry; energy; environment and natural resources; trade and promotion of investments in the region, as key areas for co-operation. This framework provides an enabling environment for cooperation in harnessing common

resources such as microbial resources for improvement of human life. The New Partnership for African Development (NEPAD) recognizes science and technology as central to its goals of promoting economic recovery, poverty reduction, better human health, good governance and environmental sustainability. NEPAD considers biodiversity and related science, technology and biotechnology to be a means to overcome the main challenges that hinder developing countries such as Uganda from achieving a higher levels of scientific and technological development and is committed to support innovation hubs of technology incubators and to support human resource development for Science and Technology.

Financial Investment in microbial resources in Uganda

Investment in conservation and utilisation of microbial resources is a very expensive venture not only for Uganda and requires concerted efforts among the various stakeholders. The government of Uganda has the foremost role in creating investment opportunities in meeting one of her constitutional obligations of promoting the rational use of natural resources so as to safeguard and protect her biodiversity (The Uganda Constitution, 1995) besides meeting her international obligations under the CBD. The government must therefore take a lead and set aside funds to conserve and utilise her microbial resources. In doing this the government can enter partnership with both local and international industry as well as international funding agencies, NGOs and other interested stakeholders. In achieving her strategic development objective, i.e to eradicate poverty (PEAP, 2000), the unique microbial resources in Uganda offer a strategic advantage in the global setting.

Conclusions

Uganda has a richness of microbial resources in her unique terrestrial and aquatic biodiversity. Despite this, Uganda still remains one of the poorest countries. It is important to take strategic advantage of these microbial resources to improve the livelihoods of the people. There is need for accelerated research on microorganisms and for the establishment of centers of excellence for taking a lead in the exploitation of the wealth of microbial resources in medical, agricultural, industrial and other areas of biotechnological importance. Financial and legal mechanisms to support the national priotised needs and goals should be exploited. Action plans for the protection, conservation, and sustainable utilisation of microbial resources in Uganda should be included in the national biodiversity and action plan (NBSAP) through extensive consultations with all stakeholders. The required core capacity of microbial scientists needs to be defined and supported through training opportunities. Information accruing from the various research projects should be linked and disseminated quickly as they are very essential in further scientific or industrial development research. Sustainable exploitation of microbial resources will provide the solutions to natural resource depletion, environmental, agricultural, food, forestry and public health concerns and help to alleviate poverty and boost Uganda's economy.

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