Agricultural biotechnology R&D and innovations in Nigeria

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Abstract: This study examined the nature and extent of the agricultural biotechnology R&D and innovations in Nigeria. Data were collected from the Directors, Heads of Crop Units and Research Scientists in the agricultural research institutes using structured and unstructured questionnaires and interview schedules. The data collected were analysed using frequencies, means and percentages.

The study revealed that there were 48 researchers engaged in the various aspects of agricultural biotechnology R&D, in the research institutes considered. About 32.9% were females, 67.1% were males with mean ages of 38 and 39.5 years, respectively. The majority, 53.2% of the researchers, possessed MSc qualifications with 46.6% specialising in conventional biotechnology. A total of 308 research outputs were recorded in all the research institutes. The most important motivation for embarking on these research projects was the need of the market (72.1%) and the existence of facilities (27.9%). The various bodies responsible for commercialisation of research results were the research institutes (83.3%), entrepreneurs (6.7%), the financial institutions, cooperative farmers and the National Seed Service (3.3%). Only two scientists possessed intellectual property rights and received royalties regularly. However, the majority did not patent their research results because of the lack of interest (45.4%), ignorance (32.0%) and the rigours of the procedure (32.3%).

Keywords: agricultural biotechnology; R&D and innovations; motivation; commercialisation of R&D results; intellectual property rights; patents; royalties; policy implications.

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1 Introduction

Biotechnology may be defined as 'the processing of materials by biological agents'. The biological agents being microorganisms, cultured cells and enzymes (Bull, Holt and Lilly, 1982). Biotechnology includes industrial activities based on fermentation, cell-culture and biocatalytic processes and those areas which involve the application of cellular and molecular biology. It also embraces emerging biotechnology, which is the integrated use of biochemistry, microbiology and engineering science in order to achieve the technological applications of the capacity of the microbes and tissue cells (UNIDO, 1989). From the above definitions, biotechnology can be broadly divided into two parts, traditional and modern. Traditional biotechnology exists where the manipulations of the biological objects are carried out with the full knowledge of the underlying scientific principles.

Modern biotechnology has been classified as cell fusion technology, bioprocess technology and recombinant DNA technology or r-DNA (OTA, 1984). Cell fusion technology is the artificial combination of different cells, into fused cell or hybridoma which allows their desirable properties to be exploited. Bioprocess technology is the use of biological processes for large-scale industrial purposes. It typically involves the reproduction of cells and microorganisms in an appropriate environment and the subsequent extraction and purification of the desired biological substances. Recombinant DNA technology (r-DNA) allows the combining of genes of different organisms within an organism, such that the organism is able to produce biological molecules, which it does not normally create.

The genetic engineering or r-DNA techniques have applications in areas of health, agriculture, and various industrial processes.

Plant improvement by the traditional methods of selection and crossbreeding is as old as agriculture itself. However, these methods have been improved upon in the light of recent advances in the knowledge of genetics and physiology of plants. The effects have been the increase in the varieties and per hectare yields of crops such as maize, wheat and rice. For example, the International Rice Research Institute (IRRI), Philippines, has a collection of over 60,000 varieties of rice (Senez, 1987). In addition to improving yield, the main purpose of selection is to obtain new varieties, which are resistant to parasites, as well as bacterial and viral diseases.

A number of new techniques have been developed with the aim of reducing considerably the time needed for a new variety to be put on the market and brought into large-scale cultivation. They also make possible, crossbreeding of species that are too far apart for normal sexual reproduction, thereby creating an entirely new plant variety. The techniques are:

- vegetative hybridisation
- in-vitro vegetative propagation
- in-vitro production of haploid plants
- somatic hybridisation
- genetic engineering.

The first major successes of plant improvement were achieved by means of vegetative hybridisation of cereal seedlings. This method consists of crossbreeding between plants by the elimination of self-fertilisation. As a result, many varieties of cereals and other plants have now been commercialised. Research work on the selection of new, high-yielding cereal varieties started after the second World War with the selection of wheat and rice from Mexico and Philippines, respectively. These new cultivars were then disseminated throughout the world (Borlaug, 1983). The successful introduction of these cultivars in several countries of Asia and Latin America led to the scheme known as the 'Green Revolution', in the mid 1960s (Sasson, 1988).

The in-vitro vegetative propagation or micropropagation by the culture of the meristem or other plant tissues has advantages over plants obtained from sexual reproduction in that the plants are free of pathogenic contaminants especially of viruses (Senez, 1987).

Somatic hybridisation, which involves the fusion of plant cells from different plants results in the regeneration of plants that are crossbreeds. The advantage of somatic hybridisation is that apart from the transfer of the genetic characteristics borne by the chromosomes of the nucleus, those specialised parts of the cell contained in the cytoplasm, such as mitochondria and chloroplasts, are also transferred. The latter are responsible for the photosynthesis, the assimilation of carbon dioxide and resistance to herbicide, diseases and drought (Senez, 1987).

Clonal micropropagation is extremely important for the preservation of genetic resources – both scarce, disappearing species and unique genotypes obtained through hybridisation and mutagenesis. Somaclonal variations – a broad variety of plant generations, is the starting point for the breeding forms which retain all possible characteristics of the variety along with the additional sought-for viable traits. It is difficult to obtain such a combination of agriculturally valuable traits through the traditional breeding methods. Bufenko and Shamina (1987) reported the breeding of plants combining high productivity with the resistance to fungi and viruses from potato somaclones in the USSR. The obtaining of guarantee harvests in zones where agriculture is exposed to risks is one of the most serious problems facing agriculture. Somaclones variations provide excellent materials for breeding plants that are both productive and resistant to stress, thereby overcoming these risks. For example, in the Soviet Union, the most important quality a plant can possess is, immunity to salty conditions. The solutions to this problem have been found by cultivating cells in media with a high concentration of salt and together with somaclonal conduct controlled breeding of modified cell lines and subsequently of modified plants with these valuable traits.

The genetic engineering of plants began in 1983 when it was reported that the Ti plasmid of *Agribacterium tumefaciens*, a common soil bacterium could be modified to allow transfer of foreign DNA into the plant genome (Zambrysky *et al.*, 1983). In addition, it was demonstrated that an antibiotic resistant marker could be used for the selection of transformed cells, which ultimately regenerated into normal fertile plants (Bevan, Flavell and Chilton, 1983). This led to many technological breakthroughs in the laboratory such as engineered resistance to plant viruses, insect resistance based on expression of *Bacillus thuringiensis* proteins, tolerance to various herbicides, control of fruits ripening and softening in tomatoes, engineered male sterility and restoration, modified carbohydrate composition and altered oil composition (Leemans, 1993). Plant varieties developed from these discoveries have been approved by the regulatory agencies and are now being grown for commercial sale (Wilkinson, 1997). Examples are, Flaur Savr™ tomato, developed by Calgene Incorporated USA, Laurical Canola Oil, Freedom II™ Squash developed by Asgrow Seed Company USA; Round-up Ready soybeans developed by Monsanto, Maximiser™ and Nature Guard™ corn by Ciba-Geigy USA and cotton species that are tolerant to insect and herbicide developed by Monsanto. Alternate vectors and other methods of transferring genes are also being developed. For example, the use of electric current to promote the incorporation of foreign DNA has been successfully applied to maize cells. Also, the use of micro particles of gold in introducing foreign genes into cassava has been perfected. One important application of gene transfer into the plant cell, is the insertion of nitrogen fixing genes (nif genes) into cereal plants. This has enabled important plants such as corn, wheat and rice to have the ability to make their own fertiliser. Papaya is one of the important, economic crops in the tropics. But papaya production is adversely affected by Papaya Ringspot Virus (PRV). This disease was reported to be extremely difficult to control and no cultivated papaya has ever shown resistance. However, some researchers in USA have recently developed transgenic papaya, with good resistance to PRV strain found in Hawaii. This application of transgenic technology is the only example in the world that has advanced to field testing (Raiman and Krattiger, 1995).

The ability of plants to survive dry conditions can also be conferred on the plant through genetic engineering. This can be achieved by isolating and cloning a gene from *Salmonella bacterium,* which has the ability to survive in salty or dry conditions. Furthermore, ‘Hup’ (hydrogen uptake) gene, which apparently helps nitrogen-fixing bacteria to use energy efficiently, has been isolated and cloned (Cooke, 1982). The World’s energy and food supplies are dependent upon the ability of green plants to convert atmospheric carbon dioxide into carbohydrates, fats and protein using light from the sun. However, the mechanism by which they consume carbon dioxide is inefficient in those plants such as wheat, barley and potatoes that are cultivated in temperate climate. Research is in progress to introduce certain genes taken from maize, which has a more efficient mechanism of carbon dioxide uptake, into temperate zone plants,. Use of selective herbicides can combat weeds, a major limitation on crop husbandry in most countries. However, these often impair the growth of the crop itself. Genetic engineering is now employed to introduce resistance gene into plants leading to the synthesis of enzymes that are sensitive to the inhibitory action of herbicide glycophosphate (Cooke, 1982).

Conventional farming has also benefited from animal biotechnology. For example, while cows produce milk in greater quantities, it is an established fact that sheep produce milk that is both more nutritious and better suited chemically for the manufacture of butter and cheese, than the milk from cows. Research programmes are in progress towards combining these traits. Genetic engineering is also being applied to increase the production of pork products, by the insertion of a gene into pigs that boosts production of growth hormones. It is now possible to market the animals in 17 weeks instead of the current 22 to 25 weeks (Raines, 1988).

The knowledge of genetic engineering is also employed in the improvement of 'biological insecticides' – microbes that attack pests – and have enormous ecological advantages over their chemical counterparts. For example, *Bacillus thuringiensis* has been used for many years to combat pests, but this as well as other similar bacteria and viruses, can be made more powerful by recombinant DNA. Also, researchers have discovered that frost damage to strawberries is triggered by bacteria, which act as nuclei for the formation of crystals on leaves. The cause, which is a particular bacterial protein, can now be deleted. This has made it possible to prevent costly frost damage by spraying the crops with the 'ice-minus' strain, which can outgrow the natural flora (Cooke, 1982).

There is no doubt that genetic engineering will enhance the sustainability of agriculture by solving the very problems affecting conventional farming, and will save farmers of the developing world from low productivity, poverty and hunger (Gresshoff, 1996). However, the problems with the application of this technique in developing countries are enormous. Planting biotechnologically improved seeds and other materials is an expensive venture, which cannot be afforded by many farmers in developing countries. For example, the seeds from tissue cultured plants are expensive so also are the genetically engineered seeds. Recent studies (Irefin, 2003) showed that in Nigeria, most farmers could not adopt the biotechnologically improved crop and varieties because of lack of money to buy the seeds and maintain them. Generally, modified seeds and planting materials need adequate water through irrigation, fertilisers, pesticides and herbicide applications, which cost a lot of money. The reagents and enzymes needed are also very costly and because of their unstable nature, they cannot be stored for a long time. Also, the laboratories must be well staffed and fully equipped (UNDP, 1989). However, such laboratories are mainly located in the industrialised countries. Genetically engineered seeds can cause reduction in genetic diversity and make the agroecosystem highly vulnerable to pests and diseases. It can also cause a decrease in ecosystem productivity due to overuse of resources (Mander and Goldsmith, 1996).

The biotechnology crops, which produce their own insecticides, closely follow the pesticide paradigm, which is itself rapidly failing due to pest resistance to insecticides. Just as insects develop resistance to insecticides with time, so also do they develop resistance to the insecticide in biotechnology crops, with time (Alstad and Andow, 1995). Biotechnology crops violate the basic and widely accepted principle of 'integrated pest management' (IPM), which is the reliance on only single pest management technology that tends to trigger shifts in pest species or the evolution of resistance through one or more mechanisms (NRC, 1996).

Recent evidence has shown that, there are potential risks in eating food derived from genetically engineered crops as opposed to naturally occurring food crops. An example of such a risk is that, the new proteins produced in such foods could act themselves as allergens or toxins, alter the metabolism of the food plant or animal, causing it to produce new allergens or toxins or reduce its nutritional quality or value. For example, herbicide resistant soyabean contains less isoflavones, an important phytoestrogen present in the conventional soyabean believed to protect women from a number of cancers (Altieri and Rosset, 1999). Ecological theory predicts that, the large-scale landscape homogenisation with transgenic crops will exacerbate the ecological problems already associated with monoculture agriculture. Expansion of this technology into developing countries may not be desirable. There is strength in the agricultural diversity of these countries, and it should not be inhibited or reduced by extensive monoculture, especially when consequences of doing so result in social and environmental problems (Altieri, Rosset and Thriepp, 1998).

However, the benefits that accrue to the countries that have been actively engaged in biotechnology are immense, especially in agriculture. However, Nigeria is yet to reap these benefits of biotechnology. That is not to say that the country is totally inactive in this field. The fact is that, there were no empirical studies on the impacts of biotechnology in the area of agriculture. For example, there is little information on biotechnology R & D and innovation activities in agriculture.

In Nigeria, as in most developing countries, the main occupation of the people is agriculture and about 65% of the population is engaged in it (Onuorah, 1999). However, despite the natural endowment the country has in this area, the food production is deteriorating (Ogbonna, 1999). Also, with increasing rate of population growth and the consequent pressures for competing socio-economic demands for land over time, the already limited cultivable land is being drawn from its traditional agricultural uses, with a resultant reduction in land-man ratio such that the average size of the farm land is now very small indeed. Table 1 shows the projected trend in land-man ratio (in hectares per farmer) for Nigeria. This declining pattern of food production needs to be reversed through modernisation of agriculture, in order to prevent food scarcity, malnutrition and other diseases, as a result of poor feeding and undernourishment. Even though the agricultural research institutes had recorded a number of successes in agricultural biotechnology R&D and innovations, the effects have been minimal. The agricultural biotechnology R&D and innovations, if properly managed, will increase the level of production by increasing the yields and the nutritional levels of the crops. Nigerian export potentials and the provision of raw materials for the agro-industries will also get a boost by way of increased productivity.

The objective of this research was therefore to:

- investigate the nature and extent of agricultural biotechnology R&D in Nigeria
- design a policy framework for the promotion of agricultural biotechnology in the country.

Table 1 Nigeria's population, area and land-man ratio

Year	*Land Area (million hectares)*	*Estimated Population of Farmers (millions)*	*Land-man Ratio (ha/farmer)*
1963	98.321	36.2	2.73
1991	98.321	57.6	1.71
1992	98.321	60.0	1.67
1993	98.321	60.5	1.63
1994	98.321	62.0	1.59
1995	98.321	63.5	1.55
1996	98.321	65.1	1.51
1997	98.321	66.7	1.47
1998	98.321	68.4	1.44

Source: Adapted from Projections of the National Population Commission
CBN Statistical Bulletin June 1993

2 Methodology

The study covered all the Nigerian Agricultural Research Institutes employing the techniques of biotechnology in the breeding of plants.

Table 2 The Nigerian agricultural research institutes

Names of the Institutes	*Acronyms*	*Location*
Nigerian Institute for Oil Palm Research	NIFOR	Benin City
Nigerian Institute for Horticultural Research	NIHORT	Ibadan
International Institute for Tropical Agriculture	IITA	Ibadan
Cocoa Research Institutes of Nigeria	CRIN	Ibadan
Institute for Agricultural Research and Training, Ahmadu Bello University	IAR/ABU	Zaria
Institute for Agricultural Research and Training, Obafemi Awolowo University	IAR & T	Ibadan
National Centre for Genetic Resources and Biotechnology	NACGRAB	Ibadan
National Cereal Research Institute	NCRI	Badeggi
National Roots Crops Research Institute	NRCRI	Ummudike

Data for the study were collected through a detailed sampling procedure as well as design and administration of questionnaires.

The nine agricultural research institutes involved in biotechnology R&D and innovations in Nigeria that were purposively selected for the study, are shown in Table 2.

At the research institutes, data were collected from three directors/assistant directors, 16 heads of the crop units, 48 research scientists and other cadres of staff involved in biotechnology. In addition to the questionnaires, personal interviews were conducted.

Structured and unstructured questions and personal interviews were employed to elicit information about the objective of the study. The directors and chief executives of the agricultural research institutes were asked about the funding of R&D research generally, and biotechnology R&D in particular. Other questions are on staff strength of the biotechnology R&D department, the products developed from the biotechnology R&D efforts, number of R&D results commercialised, existence of special outfits for technology promotion. The respondents were requested to supply any other information that could be of relevance to the study.

Information was also elicited from the heads of crop units and R&D scientists, on the nature and types of the biotechnology R&D that were being carried out in the institutes. That is, whether it is conventional (selection and crossbreeding) or modern (cell and tissue culture, vegetative propagation or micropropagation; somatic hybridisation and genetic engineering).

3 Results and discussion

3.1 Distribution of researchers by institutes, gender and age

There were altogether 48 researchers who were engaged in the various aspects of agricultural biotechnology R&D out of which 31.25% were female and 68.75% were males in the various institutes under study. The age ranges for the female and male researchers were 20–56 years and 20–59 years respectively (Table 3).

Table 3 Distribution of researchers by institutes, gender and age

Name of Institute	*Department*	*Number of Researchers*				*Age Distribution*	
		Males	*Females*	*Total*	*%*	*Males*	*Females*
IAR/ABU Zaria	Plant Science	7	2	9	25.71	40–45	40–45
NIHORT, Ibadan	Crop Improvement	4	0	4		25–40	25–36
	Genetic Resources and Biotechnology	1	1	2	20.0	–	28–36
	Vegetable Improvement	–	1	1			
NIFOR, Benin City	Technology	2	–	2	8.57	28–55	
	Biology and Crop Production	1	0	1		36–51	–
CRIN, Ibadan	Plant Breeding	5	0	5		–	40–49
IAR&T/OAU Ibadan	Cereal Improvement	–	1	1		–	20–29
	Tissue Culture Lab	–	2	2	14.29	–	30–39
	Grain/Legume Improvement	2	–	2		50–59	–
NACGRAB, Ibadan	Seed Lab	1	–	1	8.57	20.29	–
	Agriculture and Nature Science	1	1	2		30–39	30–39
NRCRI Ummudike	Tuber Crop Research	–	1	1	2.86	–	55
NCRI, Badeggi	Oil Seed Research Programme	1	–	1	5.71	35–54	
	Rice Research	1	–	1		30–39	–
	Total	26	9	35			
		(74.29%)	(25.71%)		100%		

Out of the 35 biotechnology researchers, the Institute of Agricultural Research, Ahmadu Bello University (IAR/ABU) had the highest percentage (25.71%) followed by the Nigerian Institute for Horticultural Research, Ibadan (NIHORT) (20.0%), the Institute of Agricultural Research and Training (IAR&T), Obafemi Awolowo University, Ibadan, and Cocoa Research Institute of Nigeria had 14.29%, also the Nigerian Institute for Oil Palm Research and the National Centre for Genetic Resources and Biotechnology (NACGRAB) had 8.5% each. Other institutes – the National Root Crops Research Institute and National Cereal Research Institute had 2.86% and 5.71% respectively. The higher figures of researchers recorded for the IAR/ABU and NIHORT could be due to their ability to attract researchers and retain them. This may be in terms of providing excellent facilities and good working environment conducive for research. It may be influenced by the various mandate crops that each institute is expected to research into and the extent of its activities.

For example, NIHORT's mandate include research into the improvement of various species of vegetable and fruits, and for IAR/ABU, the crop mandate include groundnut, cotton, millet, wheat, guinea corn and crops. The affiliation of IAR to the Faculty of Agriculture of Ahmadu Bello University could also contribute to its high staff strength in agricultural biotechnology. NACGRAB is established specially for biotechnology research. However, its inability to appoint more staff may probably be due to its present level of activity, which is very limited. It may also be due to the dearth of researchers in the field of biotechnology, as is being currently experienced in Africa.

3.2 Qualifications of researchers and their areas of specialisation in agricultural biotechnology

The qualifications of researchers and their areas of specialisation in agricultural biotechnology and other related areas shown in Tables 4 and 5 indicate that, majority of the researchers had MSc (51.43%), and PhD (40%) as their highest qualifications in biotechnology and other related fields. This trend is expected because biotechnology R&D and innovations has high scientific R&D content and requires availability of highly qualified manpower that could handle very sophisticated equipment and processes. This outcome emphasises the need for investment in capability building, most especially human resources development in this discipline. Hence, for any meaningful research output to be achieved the research institutes must be adequately staffed with highly qualified biotechnologists.

Majority of the researchers (60.0%) work in the area of conventional biotechnology which involves crossbreeding techniques, stem cutting, grafting among others.

These may not be considered as part of modern biotechnology. About 14.29% in recombinant DNA technology, 20% in plant tissue culture; and 5.70% in cell fusion technology. These low percentages of scientists specialising in these various aspects of modern biotechnology in developing countries, especially in Africa, had been attributed to paucity of personnel trained in the field (Okafor, 1994). For example, Okafor (1994) reported that Africa had only one hundred and six (106) trained modern biotechnologists; out of which Nigeria had about ten (10) scientists trained in gene cloning.

Table 4 Qualifications of researchers in agricultural biotechnology and other related areas

Qualifications	*Frequency*	*Percentage*
HND	1	2.86
BSc	2	5.71
MSc	18	51.43
PhD	14	40.00
Total	35	100

Table 5 Distribution of researchers by areas of specialisation in biotechnology

Areas of Specialisation	*No. of Scientists*	*Percentage*
r-DNA Technology	5	14.29
Cell Fusion Technology	2	5.71
Conventional Biotechnology	21	60
Plant Tissue Culture	7	20.00
Total	35	100%

4 Motivation for embarking on research projects

Table 6 shows that 74.28% of the research projects embarked on by the scientists was in response to the market needs and 25.72% was technology driven (technology push). The high percentage of market driven projects observed at the institutes could be explained in terms of their research mandate and their strong linkage with the users (farmers) of their R&D results. Each research institute as earlier mentioned, has mandate crops on which to carry out research, and the findings should be disseminated to the farmers. For example, CRIN, Ibadan, has cocoa, kola, tea, cashew and coffee as its mandate crops. Also, the research institutes have extension units staffed with well-qualified personnel, and strong links with the Agricultural Development Programmes (ADPs) of states where their mandate crops are grown. These had facilitated R&D result disseminations and strong feed back from the farmers, especially in the area of continuous improvement of crops such as maize, cassava, cocoa, sorghum, millet, yam and potatoes among others.

Table 6 Motivation for embarking on research projects

Description	*Respondents*
Need of the market (market pull)	74.28% (World Intellectual Property Organization, 1997)
Existence of facilities (technology push)	25.72% (Bevan, Flavell and Chilton, 1983)

4.1 The Research outputs of the research institutes, numbers of products developed, commercialised and non-commercialised inventions

The total research outputs recorded for all the research institutes surveyed was 235, out of which IAR/ABU, Zaria, had the highest (41.70%); followed by the CRIN, Ibadan (17.87%), NRCRI, Ummudike (13.19%), NIHORT, Ibadan (11.90%), NIFOR, Benin City (10.21%), NCRI, Badeggi (2.98%), IAR&T/OAU, Ibadan (1.70%) and NACGRAB, Ibadan (0.43%) Table 7.

Similarly, IAR/ABU, Zaria had the highest percentage of new products (41.46%), this is followed by CRIN (19.51%), NIHORT and NIFOR 12.20%, IAR&T (7.32%), NRCRI (4.88%), NCRI (2.44%) and NACGRAB (0%). The outstanding performance of IAR/ABU, could be due to its unique relationships with the Faculty of Agriculture of the University and its ability to attract research grants from outside the University. This same situation would have been expected of IAR&T/OAU, Ibadan, also affiliated to the Faculty of Agriculture of Obafemi Awolowo University, but the distance between the Institute and the Faculty of Agriculture of the University may be limiting their research interactions. The situation as regards research grants in IAR/ABU, Zaria, is in contrast to those of other research institutes most of which depend on financial allocations from the Federal Government. The extremely low performance (0%) of NACGRAB in new product development may be due to its relatively young age. The institute was established in 1987 and the facilities required for active R&D are not yet in place.

Table 7 The distribution of research outputs, number of products developed, commercialised and non commercialised inventions among the agricultural research institutes

S/No	*Institutions*	*Research Output*	*No. of Products Developed*	*No. of Commercial Inventions*	*No. of Non-commercial Inventions*
1	Nigerian Institute for Oil Palm Research (NIFOR), Benin City	(10.21%) (24)	12.20% (5)	14.29% (4)	6.67% (1)
2	Nigerian Institute for Horticultural Research (NIHORT), Ibadan	11.91% (28)	12.20% (5)	17.86% (5)	0% (0)
3	Cocoa Research Institute of Nigeria, (CRIN), Ibadan	17.87% (42)	19.51% (8)	14.29% (4)	33.33% (5)
4	Institute for Agricultural Research A.B.U. Zaria	41.7% (98)	41.46% (17)	42.86% (12)	33.33% (5)
5	Institute for Agricultural Research and Training O.A.U., Ibadan	1.70% (4)	7.32% (3)	7.14% (2)	6.67% (1)
6	National Centre for Genetic Resources & Biotechnology Ibadan	0.43% (1)	0% (0)	0% (0)	0% (0)
7	National Cereal Research Institute Badeggi	2.98% (7)	2.44% (1)	3.57% (1)	6.67% (1)
8	National Root Crops Research Institute Ummudike	13.19% (31)	4.88% (2)	0% (0)	13.33% (2)
		(235)	(41)	(28)	(15)

Similarly, IAR/ABU, Zaria, had the largest percentage (42.86%) of innovations followed by NIHORT, Ibadan (17.86%). Some of the commercialised products of the IAR/ABU include high yielding wheat, cotton (Samcot-9 and Samcot-10), early, medium and late maturing groundnut, sorghum, maize, kenaf (Sam-ken) and new varieties of cowpea which are resistant to biotic and abiotic factors (Table 8).

NIFOR, Benin City, had 14.29% of all innovations in agricultural biotechnology. The centre had commercialised four products namely, disease tolerant oil palm, coconut, date and raphia seeds.

CRIN, Ibadan, which had a similar percentage (14.29%) was established in 1964, and has a mandate to undertake research into and provide information and services relating to the production of cocoa, coffee, kola, cashew and tea. The institute has developed and commercialised improved, high yielding varieties of cocoa, kola, cashew, coffee and tea. It had also developed improved propagation techniques for these crops.

The IAR&T/OAU, Ibadan, had 7.32% of all the products developed and 7.14% commercialised research efforts. The institute had developed varieties of sweet corn, western yellow- popcorn and commercialised only the two corn maize varieties.

The NCRI, Baddegi, had 2.44% share of all the developed products and 8.57% commercialised invention of the research institutes in agricultural biotechnology.
The centre's main concern has been to improve the quality and quantity of cereals in Nigeria, and it has been able to develop and commercialise improved variety of rice from crosses of O. sativax and O. glaberrima (Table 8).

Table 8 Some of the products developed/commercialised by agricultural research institutes

S/No.	*Institutes*	*Products Developed*	*Product Commercialised*
1	Nigerian Institute for Oil Palm Research (NIFOR), Benin City	Disease-tolerant oil palm, coconut, date and raphia seeds.	Disease tolerant oil palm, coconut date and raphia seeds.
2	National Cereal Research Institute (NCRI), Badeggi	Fertile hybrid from *Oryza sativax*, *Oryza glaberrima* crosses.	Fertile hybrid from *O. Sativax*, *O. glaberrima* crosses.
3	Nigerian Institute for Horticultural Research (NIHORT), Ibadan	Proven lines of pepper, tomato and okro, rapid on farm propagation of plantain/banana, mango. On field forcing (flower induction) of pineapple.	Pepper, tomato and okro, rapid on farm propagations of plantain/banana/mango. On field forcing (flower induction) of pineapple.
4	Cocoa Research Institute of Nigeria (CRIN) Ibadan	Improved high yielding varieties of cocoa, improved genotypes of *cola nitida*, high yielding cashew genotypes, cross breeding of quillo and java coffee for improved yield.	High yielding varieties of cocoa, *cola nitida* and cashew, High yielding coffee from crossbreeding of java and quillo varieties.
5	Institute for Agricultural Research ABU, Zaria	Wheat crops (3 varieties), Barley (3 varieties) Cotton (Sam-Cot-9 Sam-Cot-10) Kenaf (Sam-Ken1) (Sam-ken2) Sunflower, Pepper, Early Median and late maturing groundnut varieties. Late maturing rosette resistant varieties of groundnut, High yielding sorghum hybrid. Sorghum developed for making beer (SSV), Maize varieties (3), Cowpea varieties with resistance to biotic and abiotic stress.	Early, medium and late maturing groundnut varieties. Late maturing resette resistant varieties of groundnut sorghum hybrid, Wheat (3 varieties), Pepper.
6	Institute for Agricultural Research and Training, OAU, Ibadan	Western yellow and pop corn, sweet corn	Western yellow and pop corn.
7	National Root Crops Research Institute, Ummudike	Cassava as gelling agent in tissue culture media, alginate as gelling agent for protoplast-culture	

The NRCRI, Ummudike, despite its mandate, which covered a wide range of root crops, contributed only 4.88% of the number of new biotechnology products from the research institutes. The interview conducted, showed that the institute was not able to retain many of the trained staff in its agricultural biotechnology programme, due to poor conditions of service, and lack of necessary equipment and facilities for research. The centre is mandated to research into tuber crops like cassava, yam, cocoyam, potato, and ginger. It had developed cassava as a gelling agent in tissue culture media, and alginate as gelling agent for protoplast culture.

5 Commercialisation of research results/inventions by various bodies

The research institutes were responsible for 90.48% of the commercialised inventions, probably because most of them had commercial (extension) units, which serve as outlets for the diffusion of their innovations (Table 9). The industry had not assisted research institutes in the commercialisation of biotechnologically modified agricultural crops. This is in contrast to what occurs in some other developing countries like Brazil, where a private company such as Biomatrix S.A., was involved in R&D activities on the micropropagation and commercialisation of potato, and temperate and tropical fruit species. In advanced countries, many companies had sponsored and commercialised research results in agricultural biotechnology. Examples are Monsanto, Calgene, Asgrow Seed Company USA, Ciba-Geigy USA, Novartis, Du Pont, Zeneca, etc.

The involvement of the entrepreneurs in the commercialisation of research results from the research institutes was very low (4.76%). This shows that Nigerian entrepreneurs are not usually interested in experimental development which is a risk, but instead, they prefer to invest in already proven innovations or in buying and selling of finished foreign goods which will attract quick profits.

The financial institutions in Nigeria had not been involved in the commercialisation process (0%). According to the respondents, the banks were usually reluctant to grant loans to researchers, entrepreneurs and prospective investors unless the loans are for ventures that had been time tested and found to be profitable and would repay the loans in the shortest possible time. Individual scientists could not commercialise their inventions, because the process requires a lot of investments, which many scientists may not be able to afford. Also, the burden of the risks of failure will be too much for individuals to bear. However, the National Seed Service made its contributions (4.76%) in the commercialisation of research results of the institutes.

Table 9 Commercialisation of research results/inventions by various bodies

Bodies	*Numbers of Research Results/Inventions Commercialised*	*Percentages*
Research institute	19	90.48%
Industry	0	0%
Incubation centre	0	0%
Entrepreneurs	1	4.76%
Financial institutions (World Bank)	0	0%
Self	0	0%
Others: National Seed Service	1	4.76%
Total	21	

6 Possession of intellectual property rights and receipt of royalties by research scientists

Table 10 shows that 14 scientists had inventions to their credit in the various agricultural research institutions. Three (21.43%) of these researchers possessed intellectual property rights conferred by statute on an individual as corporate body with respect to the product of his or her intellect, guaranteeing the exclusive control of the exploitation of that property, but none (0%) of the owners of intellectual property rights received royalties regularly. Most of the researchers (42.86%) who had their inventions commercialised were from IAR/ABU, Zaria. This is followed by NIFOR, NIHORT, CRIN with two researchers each (14.29%). At NACGRAB, Ibadan, there was no scientist with innovations, and none of its scientists possessed intellectual property rights and therefore, no recipient of royalty. In all, there were three research scientists (21.43%) who possessed intellectual property rights on commercialised research results/inventions. Majority of them neither possessed intellectual property rights nor received royalties (Table 10).

Table 10 Respondents possessing intellectual property rights and the receipt of royalties in the various research institutes

S/No.	*Institution*	*Percentage of Scientists with Inventions*	*Percentage with Intellectual Property Rights*	*Percentage without Intellectual Property Rights*
1	Nigerian Institute for Oil Palm Research, Benin-City	14.29% (2)	0% (0)	18.18% (2)
2	Nigerian Institute for Horticulture Research, Ibadan	14.29% (2)	33.33% (1)	9.09% (1)
3	Cocoa Research Institute of Nigeria, Ibadan	14.29% (2)	33.33% (1)	9.09% (1)
4	Institute of Agric Research ABU Zaria	42.86% (6)	33.33% (1)	45.45% (5)
5	Institute of Agriculture Research and Training, Ibadan	7.14% (1)	0% (0)	9.09% (1)
6	National Centre for Genetic Research and Biotech, Ibadan	0% (0)	0% (0)	0% (0)
7	National Cereal Research Institute, Badeggi	7.14% (1)	0% (0)	9.09% (1)
8	National Roots Crops Research Institute, Ummudike	0% (0)	0% (0)	0% (0)
	Total	14	3	11

7 Reasons for not patenting research-by-research scientists

About 55% of the research scientists claimed that their engagement in agricultural biotechnology R&D and innovations was mainly for promotion, in order to enhance their status in their careers (Table 11). This is unlike the developed and newly industrialising countries where research outputs are directed towards commercialisation in order to gain competitive advantage and improve the economic well being of the populace. Recent studies and experience show that the contribution of raw materials and labour has steadily declined in proving competitive to the products, while innovations and creativity bring competitive advantage to companies and nations (World Intellectual Property Organization, 1997).

About 15% of research scientists in biotechnology were ignorant of the procedure for patenting under the Nigerian legal system, while 30% claimed that the procedure was too rigorous. Probably these scientists (45%) were interested in the commercialisation of their inventions but could not do so for the reasons stated above. By Section 1 of Nigerian patent law, an invention is patentable if it is new; if it results from inventive activity and is capable of industrial application. An invention is also patentable if it constitutes an improvement upon a patented invention and is new, results from inventive activity and is capable of industrial applications (Chukura, 1982).

Table 11 Response to reasons for not patenting invention by research scientists

Reasons for Not Patenting	*Frequency*	*Percentage*
Not interested in commercialisation	0	0%
Do not know procedure	(3)	15.00%
Procedure rigorous	(6)	30.00%
Just for promotion	(11)	55.00%
Total respondents	20	100%

8 Conclusion and policy implications

This study brought into focus the need to strengthen capacity building in the areas of agricultural biotechnology. This can be achieved by encouraging doctoral and post-doctoral training through scholarships, awards and fellowships for studies abroad, and in the country. Formal departments of biotechnology should be established in some Nigerian Universities and the existing ones in related areas should be strengthened. These departments should be well equipped to offer degrees and short-term courses in biotechnology. Since majority of the researchers specialised in conventional biotechnology, there is urgent need for the re-training of these conventional biotechnology experts in order to acquire the necessary skills required in modern biotechnology, especially in the areas of genetic engineering, r-DNA, bioprocess and cell fusion technologies. As a short-term measure, the Nigerian diaspora knowledgeable in the field could be encouraged to organise such trainings and workshops in the country. This will go a long way in the development of the critical mass of human resources required in this field for the improvement of the agricultural production that will ensure food security in the country.

The strategies employed in the commercialisation of the research findings by the agricultural research institutes should be overhauled. According to Kumuyi (2001), this situation whereby researchers and research institutes tend to conduct their investigations even up to pilot stage within the confines of their laboratories and then try to sell the idea to entrepreneurs (technology push), often ends up in failure. This problem can be overcome with greater interaction between researchers and entrepreneurs, right from initial stages of the projects. The government can also play a leading role in the promotion of these linkages by setting up of the industry/research institute cooperative research centres, such as technology incubation centres and science and technology parks. The Federal Government has established about 15 technology business incubation centres in various parts of the country. More of them should be established and well equipped. They should be officially linked with universities and research institutes. These linkage centres will also promote market driven research, which will solve the industry's problems. Also, the government can fund a series of national technology priority projects in which grants and soft loans are provided to groups of interested companies that agree to cooperate for a specific period in the development of specific technologies, working in collaboration with R&D personnel from the academics.

The Government should mount an enlightenment campaign in order to educate the public in general, and the research scientists in particular, about the patent law in Nigeria and the benefits that could be derived from patenting research outputs. The patent law does not recognise an employee's rights to a patent – the employee has the right to compensation whenever an invention is made by him particularly if it has outstanding benefit to the employer. This may discourage serious research and dampen the enthusiasm that any brilliant researcher may have concerning his work. This patent law needs an urgent review to conform to what obtains in advanced countries.

Apart from encouraging patenting of research results, the researchers should also be given special rewards whenever they make an outstanding performance in their research work. This could be in terms of monetary rewards or accelerated promotions.

Collaborations and networking among researchers should be encouraged by all the research institutes in the country. The networking and collaboration could be extended to similar institutions abroad. This will not only eliminate duplication of research efforts, but will also enhance the quality of research outputs.

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Introduction to Agricultural Biotechnology in Nigeria. The drastic fall of oil prices in the international market has spurred the Federal Government to diversify the Nigerian economy into other sources of revenue generation, specifically agriculture.Â Agricultural biotechnology is the use of a range of tools, including traditional breeding techniques to alter living organisms or parts of organisms to make or modify products, improve plants or animals or develop microorganisms for specific agricultural uses. The undesirable characteristics of the conventional agriculture like susceptibility to diseases and low productivity are bred out. Biotechnology has especially been beneficial in improving agricultural productivity and increasing the resistance of plants to diseases. Innovation and Agricultural Biotechnology â€“ Whereâ€™s Canadaâ€™s Future? Biotechnology and a Vision for Canadaâ€™s Agriculture and Food Industries. Biotechnology is a tool, a set of techniques and approaches that allow farmers and companies to achieve clearly identified objectives. In a little over a decade that tool has reshaped Canadian agriculture, providing new crop varieties and new ways to differentiate Canadian agricultural products, as well as higher yields, greater resilience and more sustainable management practices.Â Capturing R&D investment â€ Saskatoon is now the world centre for Canola research and development and global companies like Dow and Bayer are choosing to move a major portion of their canola. research to Saskatoon to be part of the canola research cluster. The concluding edition on Innovations in Agriculture will shed more light on a few innovative strategies that can engender sustainable growth and development in the sector and by extension the economies of the different regions. Issues, concerns and challenges in the agricultural sector.Â For instance R&D has been responsible for the adoption of biotechnology in Nigeriaâ€™s agricultural production leading to the establishment of the National Biotechnology Development Agency (NABDA), as well as the National Bio-safety Management Agency (NBMA), an agency that addresses safety concerns associated with biotechnology and provides regulatory frameworks for sustainable agricultural practices.