ISSN- 2394-5125 VOL 09, ISSUE 01, 2022

Applications of Biotechnology in Agriculture

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Summary: Vietnam is a developing country with aiming for industrialization and modernization, however, agriculture still plays an important role in the economy to ensure food security and export. In order to promote Vietnam's agricultural development towards high quality and sustainable, the application of biotechnology is considered an important tool to help improve the productivity and good characteristics of food products from animals and plants. Over the past time, Vietnam's agriculture has undergone a significant change when applying biotechnological achievements to the fields of cultivation, animal husbandry, etc., thereby helping to improve productivity for agricultural production activities agriculture, creating many valuable products, saving costs for farmers, contributing to the stability and sustainability of the agricultural industry in the context of economic integration. Therefore, promoting investment in research and application of biotechnology to develop the country's economy is a right policy of the Party and Goverment.

1. Introduction

Since the early 1990s, biotechnology has been considered as one of the four major areas of technology that should be emphasized for development in order to accelerate national industrialisation and modernisation. On that basis, biotechnology initiatives and programs at the national, regional and local levels have been established towards the goals: breeding new varieties with high potential production output and economic efficiency; developing technologies for the manufacture of preparations for the care and protection of plants and animals; developing means of novel processing and preservation technologies aimed at diversification and quality enhancement of agricultural commodities for export and domestic consumption. Biotechnology has increased efficiency in agriculture by assisting in the resolution of specific issues such as productivity and disease resistance, while also demonstrating its potential to the remedy and protection of natural environment. As is the case with many other nations worldwide, Vietnam is confronted with climate change, fast population expansion, and limited agricultural land owing to urbanization, all of which contribute to a decline in agricultural production output. According to the General Statistics Office's 2009 and 2019 Population and Housing Censuses, Vietnam's population rose by roughly 10.7 million people during the last decade, from 85.5 million in 2009 to 96.2 million in 2019. As of November 2020, Vietnam is the 15th most populated nation in the world, covering an area of around 331.2 thousand square kilometers (ranked 65th in the world). Vietnam's population is predicted to surpass 100 million people in the near future, which implies that the country must secure sufficient food for this rising population. Not to mention that Vietnam is one of the five nations most impacted by climate change, with agriculture being one of the most vulnerable sectors owing to its dependences on weather, soil, and irrigation variables. Therefore, Vietnamese agriculture has sought solutions from biotechnology to develop a sustainable green agriculture, ensure national food security and contribute to global food security.

2. Impact of Science and Technology on Agriculture

Over the years, science and technology (S&T) have positively conduced to socioeconomic growth in a variety of sectors, including agriculture. According to the Ministry of Agriculture and Rural Development, S&T innovations have contributed over 30% of value-added in agricultural productivity up to the present. The application of scientific and technological advancements in agricultural production has resulted in a greater productivity, quality, efficiency, and competitiveness of agricultural commodities on both local and international markets. Many results of scientific research have been successfully transferred into agricultural production, including new varieties, technological procedures and new technical advances, all of which have led to lower investment costs, improve profitability and economic efficiency. There have been a number of high-tech farming models receiving substantial investment from both local and international business organizations. The total export turnover of agro-forestry-fishery products was estimated to be around 190.03 billion USD from 2016 to 2020, averaging 38 billion USD/year. In 2020 alone, it was estimated to be 41.25 billion USD, much higher than the 29.53 billion USD/year for the period 2013-2015. On average, in the period 2016-2020, the export value of agricultural, aquatic and forestry commodities reached

annually USD 18.6 billion, USD 8.3 billion, and USD 9.8 billion, respectively, increasing by 34.7%, 17.6% and 50.1% compared to that of the period 2013-2015. The United States, China, Japan, and South Korea are Vietnam's top four import markets for agricultural, forestry, and fisheries goods, with a market share of 26.7%, 20.5%, 8.1% and 4.9%, respectively, up by 134%, 61.6%, 45.2% and 71.1% in value compared to 2013.

3. Achievements of biotechnology in agriculture

On March 4, 2005, The Secretariat of the Central Committee of the Communist Party of Vietnam issued Directive No.50-CT/TW on accelerating biotech development and application for industrialization, which stated that biotechnology's role in agro-forestry-fisheries is to "create new varieties of plants and animals with high productivity, quality and economic efficiency." According to the proper party line, all levels and sectors have made enormous efforts to implement Directive No.50-CT/TW and achieved numerous significant successes in all areas. Animal breeds, plant varieties, biological products, new technological processes, and other innovations have been transferred and potentially adopted to agricultural production through enterprises and farmers, therefore lowering investment costs, increasing profits, and bringing agricultural production to a high level of economic efficiency. It has been shown that many models of high-tech application in agriculture, horticulture, and aquaculture have assisted in rising the economic efficiency by 10-30%; they have also contributed to changing farming habits and boosting productivity. In addition to the S&T achievements of the affiliated research units, the agricultural sector has drawn a lot of interest and large-scale investment from major domestic enterprises and corporations in the agribusiness value chain. These units have applied a variety of modern manufacturing processes, innovative and foreign technologies, all of which have positively affected on sector growth.

3.1. Horticulture and animal husbandry

The mission of biotechnology in agriculture - forestry - fishery is clearly stated in Directive No.50-CT/TW: creating new varieties of plants and animals with high productivity, quality and economic efficiency, thereby becoming part of restructuring the national economy; developing technologies in production of plant and animal protection products; agro-forestry-fisheries processing and preserving technologies aimed at product diversification with quality enhancement for export and domestic consumption. With highly precise objectives, these are the most applicable and established areas of biotechnology. Researches on technologies of cell, gene and microbiology have all been strongly promoted and applied to practical manufacturing.

To put Directive No.50-CT/TW into action, the Prime Minister issued two decisions: "Key programs and application of biotechnology in agriculture and rural development to 2020" and "Projects of development and application of biotechnology in fisheries and aquaculture until 2020." The Ministry of Agriculture and Rural Development (Vietnam) has actively collaborated with other ministries and sectors to carry out scientific and technological tasks and investment projects in equipment, as well as to organize biotechnology training programs. As a result, after 10 years of implementation of the Aquaculture Biotechnology programme, 214 scientific and technological tasks have been conducted with a total allocated budget of approximately VND 550 billion, in which 130 tasks have been accepted, while some have continued to get funding for research and development so as to produce commercial output for manufacture. Thanks to the application of numerous modern technologies in gene, cell and microbial such as plant genetic modification technology, agro-forestry plant micropropagation technology, microbial technology to produce antagonistic organisms and multi-functional fertilizers, a number of agro-forestry plant varieties with high productivity and quality, disease resistance and tolerance to adverse ecological conditions have been sucessfully developed.

For the purpose of developing genetically modified crops, scientists have concentrated their efforts on upgrading plant varieties possing the traits of fast-growing ability and resistance to pests, diseases, and environmental stressors as a means to address the rising problem of climate change. Several outstanding research achievements in selection and breeding disease-resistant crops, such as 20 transgenic soybean lines with insect resistance, 7 rice varieties with bacterial leaf blight disease resistance, 2 blast-resistant rice varieties, 4 brown planthopper resistant rice varieties, a line of pinus latteri expressing sawfly resistance genes and 8 cotton varieties with leafroll dwarf disease resistance, were sucessfully obtained by the application of genetic modification techniques and molecular markers. Besides, research projects in plant breeding attained 8 varieties of chinaberry tree that express up-regulated genes in faster-growing, 3 lines of chinaberry tree expressing genes in wood quality improvement, and 7 varieties of rice with drought tolerance. Several products obtained from these research projects have been officially recognized and put into commercial production, such as 2 drought-tolerant rice varieties (OM

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6162 and OM 7347) and a brown planthopper resistant rice variety (OM 6071), or trial production that included drought tolerant rice varieties (OM 6677, OM 7398, OM7364, OM 8928), brown planthopper resistant rice variety (KR1), aromatic rice variety (HDT8); blast resistant rice variety (NB01); leaf blight resistant rice varieties (DT45, DT57, N91, DT66); leaf blight resistant sticky rice varieties (T65, NV3) and single cross hybrid maize variety (MN-1).

It is apparent that modern technologies have made a great impact on variety selection. A myriad of promising crop varieties, such as seedless orange and mandarin varieties, 2 carnations and mutant chrysanthemum varieties that have already been put into trial production, 2 lines of doubled-haploid cucumber with female flowers accounting for >85%, and 2 doubled-haploid pepper lines with diseases resistant have been developed as a result of applying cell and gene technologies. Certain of paddy varieties, particularly including DR3 (widely cultivated in the Central Highlands) and TH-33 (hybrid rice variety of which IP rights was transfered with the value of VND 10 billion), were created by adopting effectively an advanced technique known as somatic cell hybridization. One of the notable successes of biotech application in breeding to create high-quality paddy products is the early maturing rice variety (OMCS) cultivated in the Mekong Delta. This induced a considerable expansion in cultivation area of high-quality rice varieties in the Mekong Delta from 10% in 2003 to more than 50% in 2015, with an average annual yield of 5.1 tons/ha, ranking first in the ASEAN region. Many micropropagation technologies, including those for the propagation of eucalyptus, acacia mangium, flowers, and sugarcane, have been successfully attained, transferred, and adopted in production with an annual productivity of hundreds of millions of disease-free seedlings.

At the same time, in the context of increasingly narrow agricultural land, soils are becoming severely degraded (loss of fertility, erosion and leaching) due to a combination of inappropriate farming practices, pesticide and chemical fertilizer misuse and inevitable impacts of climate change. Scientists have investigated and applied a variety of techniques for soil conditioning and develop fertilizers by using noval technologies partly contributing to the soil improvement. Biochar, microbial inoculants for soil amendments, and nanotechnology-based fertilizer synthesis are among the most prominent achivements. In the field of soil biology, the application of indigenous microorganisms has been studied with the purpose of organic matter decomposition and restoration of contaminated soil owning to toxic substances such as dioxins, pesticides, and heavy metals. Examples of other research achivements in soil conditioning include conducting the research and development of symbiotic microorganisms beneficial to plants on saline and alkaline soils; studying in the production of microbial organic fertilizers by optimization of the organic waste from agricultural manufacture and processing; and investigating the use of microbial organic fertilizers to improve soil quality, crop yield and disease control.

Agronomists have also made remarkable attainments in the area of plant disease research. Researchers in Vietnam have been able to detect accurately and rapidly a number of severe rice viral diseases, such as rice grassy stunt disease, leaf curl dwarf disease, and Southern rice black-streaked dwarf disease by using modern molecular biology techniques, thereby allowing them to forecast the possibility of disease outbreaks and reduce post-harvest losses in rice production. Additionally, these agronomic experts have mastered the technique of manufacturing diagnostic test kits for the detection of plant viruses, such as leafroll dwarf virus, rice grassy stunt virus, and Southern rice black-streaked dwarf virus. Besides, biotech advancements succeeded in inducing a number of microbiology-based solutions as a means to prevent nematodes, fungus, and pathogenic bacterium from infecting the root zone of crops such as coffee, pepper, cotton, litchi, peanuts, sesame, and maize. There also have been hundreds of functional microbiological fertilizers developed for use on vegetables, coffee, peanuts, and forest trees, as well as several preparations evaluated with great effectiveness to preserve and process fresh fruits and vegetables. In particular, many inventions so far have been granted a patent, and transferred into practical industrial-scale manufacturing. However, no little products are still at the stage where they need the active engagement of enterprises and the ongoing support of the program so as to be launched into large-scale commodity production to serve the clean and organic agriculture approaching for ecological sustainability.

3.2. Gene technology

When it comes to animal selection and breeding by using biotechnology, some fundamental research has been established on pinpointing genetic differences of domestic chicken and local cow breeds, and employing molecular markers in animal breeding. Furthermore, plenty of advanced technologies have been successfully studied and applied in domestic breeding sector along the line of innovating reproductive technologies for the selection and breeding of pigs and cows; developing the technological processes of embryo creation, embryo transfer, and cryopreservation of pig and cow; and mastering the technique of in vitro fertilization. Vietnamese scientists, in

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particular, have performed sustained efforts in recent years to approach animal cloning technology and conduct researches on embryo splitting and somatic cell nuclear transfer (SCNT). Fundamental research on the application of gene and cell technologies have been carried out so as to develop databases of genetic resources of uncommon and unique Vietnamese plants and animals through digitization. This serves as a foundation for becoming expert in technology platform along with restoration and effective exploitation of genetic resources to improve and produce commodities with particular characteristics. Several studies drawing much interest and investment in the programme include catfish genome decoded, creating a DNA barcoding database (Vietnamese DNA data bank) for species inspection and identification, genetic relationship analysis, genetic diversify, and management of agricultural and forestry plant varieties, as well as Vietnamese lobster and catfish breeds; breeding pot-bellied pig by using somatic cell nuclear transfer (cloning) technique; registering DNA sequence variants in mitochondrial D-loop region of Vietnam's golden cows, Vietnamese specialty fruits, and precious woods on Genbank with the purpose of preserving and developing traditional plant varieties and animal breeds. In addition to a number of laboratories belonging to research institutions and colleges that have engaged funding allocation, among them are labs granted with VILAS, as well as obtaining certificate and recognized equivalent from international organizations and countries in the analytical system. The research team has also approached and mastered several advanced technologies such as gene transfer in crops such as maize, soybean, pine, chinaberry, and eucalyptus with desirable characteristics, genome editing, and recombinant DNA. Thanks to the coordination and support of relevant ministries, agricultural and fisheries biotechnology program's activities have reaped encouraging results in the establishment of a legal corridor, technical infrastructure, and management system for genetically modified organisms and their products in Vietnam. In particular, the system of Vietnamese legal documents on biosafety is highly appreciated by nations around the region and the globe.

3.3. Animal husbandry and veterinary medicine

Despite a limited investment in the area of animal feed production research, certain scientific studies have obtained great results thanks to the effective application of advanced technologies. Probiotics for pigs and poultry perfectly exemplifies the potential attainment serving to lower feed consumption as well as the prevalence of digestive diseases of livestock. Several enzyme preparations that help in boosting animal weight while decreasing feed consumption have also been established in pilot production. Two probiotic preparations used in animal husbandry, PRO TM Swine and PRO TM Avian, have been registered trade names and placed into trial production. So far, up to 3550kg of probiotic preparations have been manufactured and supplemented to over 270 tons of concentrate feeds by using modern microbiological technology, thereby lowering the market's dependence on imported livestock feed. Microbiological technologies have also been applied in the production of biological preparations to control or deodorize the livestock farms.

In the field of veterinary medicine, many fundamental research discoveries on virus pathology of animal illnesses such as A/H5N1, Gumboro, duck viral hepatitis, and duck cholera also potentially be useful to the breeding of disease-free animal species, particularly in the production of vaccines for poultry disease prevention. Examples of successful achivements include the production of vaccines against avian influenza H5N1 at a volume of 200 million doses/year, as well as multivalent vaccines against a variety of infectious diseases in poultry and pigs. A number of vaccines have been studied and are projected to be self-produced, such as vaccines against foot-and-mouth disease, new influenza A/H5N1 strains, and PRRS (blue ear disease), with the objective of no more vaccine import needs.

The aquaculture and cultivation of edible and medicinal mushrooms are two more areas where biotechnology have been effectively applied. It is demonstrated that technologies in fish, shrimp and crab breeding have greatly assisted in the selection of disease-free and high-yielding breeds along the line of potentially applying molecular markers and modern molecular biology techniques. Rapid multiplication techniques for production of disease-free breeds has been strongly invested with a number of research programs, resulting in a considerable growth of economic efficiency. In the sector of mushroom cultivation, biotechnology has conduced to the development of many new mushroom varieties and propagation technologies allowed to manufacture on an industrial and semi-industrial scale. As a consequence, Vietnam's total mushroom output has so far surpassed 250,000 tons per year, contributing to an annual export turnover of over USD 90 million. Thus biotechnology in the sectors of agricultural - animal husbandry – forestry has made remarkable progress toward boosting productivity in recent years along the line of strong promotion of investment on research and application and the government's official license for the application of genetically modified crops.

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4. Limitations in the development of biotech applications and their causes

Limitations: Biotechnology has played a dominant role in the expansion of the agricultural sector, guaranteeing national food security, promoting production efficiency and income of producers, making a significant contribution to strengthening exports, and switching Vietnam to a global agriculture powerhouse. However, there have still existed certain shortcomings in the development and application of science and technology in Vietnam in general, and in the agricultural sector in particular, expressed in the following aspects:

Financial support has always been a major issue when it comes to developing and applying biotechnology in commodity production. In pursuance of Directive No.50-CT/TW objectives, a considerable amount of funds is required and must be well-managed for proper use. The funding allocated for biotech application and testing procedures, however, fails to meet demands. There have been several laboratories constructed with enormous state investment; nevertheless, high-exploitation efficiency has not been achieved due to the unreasonable planning work of defined tasks, objectives, and outputs. Our biotech human resources fails to satisfy both quantity and quality, particularly lead scientists who are accountable for research orientation. The linkages between research and manufacturing business, scientists/scientific organizations and farmer households/enterprises, have remained untied, adversely causing a waste of investment. Many innovative biotech application models have still remained in the experimental stage, and owing to a variety of objective and subjective factors, they have been sluggish to be implemented in production.

The funding allocation for biotechnology also offers several limitations. Research disciplines have been dispersed throughout various subjects, failing to emphasis on addressing urgent problems or promoting the country's natural potentials and capabilities. The dispersion of funds has also been one of the reasons why really promising studies have not been given the proper attention and investment. As a consequence, the product only reaches the intermediate stage and has yet to induce the finished product. The majority of research programs has been published in domestic journals, few of them have reached to really high-quality publications in prestigious international journals.

Additionally, we have failed to promote adequately potential sources of international collaboration serving to enhance bilateral and multilateral programs aimed at advancing the scientific competence and professional qualifications of biotech researchers. Not many trainees have been sent overseas for instruction, and the short-term training provided to specialists is only adequate in quantity but falls short in quality for each sector. Biotechnology has also suffered from a dearth of qualified scientists who can serve as mentors or project leaders, resulting in unsatisfactory research outputs in terms of both quality and quantity.

Causes:

The primary source of limitations is due to insufficient awareness of the biotech position, function, and necessity in the agriculture sector among various levels of party committees and authorities. The lack of connectivity and coordination across levels and sectors in developing specific mechanisms and policies, and executing tasks further limits the adoption of biotechnology in agricultural development. Besides, the propaganda about the achievements of biotechnology has not been widely and properly promoted. Limitations in both the quality and quantity of research staff, experts, and facilities serving biotechnology are also significant factors. The training of biotech human resources in Vietnam fails to match the country's physical production demands. To this day, we have an uncoordinated network of biotechnology research institutions with outdated infrastructure that cannot satisfy the industry's ever-changing standards.

The existing financial mechanism in Vietnam also poses a significant obstacle to the widespread application of various biotechnology in research and manufacturing. The finance mechanism applied to biotechnology research and application activities is still inadequate, has not facilitated scientists to enhance their creative spirit, and failed to motivate enterprises to invest in production and commercialization of biotech items. In addition, the compensation and benefits in Vietnam probably fails to engage the delication of scientific experts to biotech research and development. Both present and future, policies should be adopted to encourage the development of linkages between biotechnology research and implementation via investments in facilities and human resource training. Of no less significance are the deployment of policies and orientations aimed at enhancing the ubiquitous and effective application of biotech researches to physical production and sectors of social life, particularly in the agriculture.

5. Orientation for the development of biotechnology in the agriculture sector

In the coming time, it is necessary to continuously employ biotechnology's achievements to support the enhancement of country's socioeconomic efficiency.

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Firstly, the Party and State must consider investment in biotechnology development as a priority solution in socio-economic development to facilitate the establishment of a sustainable green economy. The competent authorities must check up, amend, and supplement the system of legal documents, specific mechanisms and policies on biotech research, application, and transfer. Financial support policies should be concentrated on biotechnology research and development while attaching the engagement of highly skilled biotech professionals. Furthermore, the issue of strict enforcement of intellectual property legislation in copyright protection requires significant responsibility.

Secondly, priority should be given to financing the upgrade of infrastructure and human resources training and development. It is necessary to train of biotech staffs at all stages of education, from high school through college and postgraduation. This requires a specific allocation from the locality's training budget for the training of highly qualified biotech professionals. The promotion of retraining and new training of scientists at all levels of PhD, master, bachelor, technology engineer, and technician is also attached to this effort. The training program must satisfy and be strongly associated with the practical laborers'needs to successfully deploy the application of biotechnology development in Vietnam and simultaneously prevent situations where workforce are redundant but not performing all of the job. The renovation and raising of infrastructure must be given proper investment in tune with human resource training toward the facilitation of biotechnology research and application. The system of laboratories, assessment and inspection centers in various regions must be fully equipped, uniformed and incrementally modernized to satisfy the requirements of advanced nations in the region. Facilities in local departments and agencies, in particular, must be more strongly invested aiming to the implemention of scientific and technological advances in biotechnology into local production.

Thirdly, bioindustry development should be preferentially taken into account. In the context of nonstop innovation time, it is crucial to establish a bio-based industry in association with the strong acceleration of the application of biotechnology's achievements on restructuring agricultural economics and building a new countryside. Biotech employment have positively affected on raising the quality of animal breeds and plant varieties along with boosting the sectoral productivity while also preserving the environment and guaranteeing biosecurity. The Party, State, and all levels of government must adopt the policies of engagement and funding sources diversification for scientific research, focusing on the production of essential biotech products, encouraging the linkages between the activities of scientific research and manufacturing business, facilitating human resource training, disseminating and transfering technological advances, so that biotechnology can potentially come into practical production and significantly contribute to socioeconomic growth. In particular, applied reseach programs along with pilot production in the biotech sector should be prioritized for compensation in the terms of investment and assistance without recovery or with a low recovery rate to encourage the development of the bioindustry.

6. Conclusion

As a final observation, the development and application programs of biotechnology in agriculture commodity production has reaped encouraging results. These achivements have been expressed in the remarkable upgrade of productivity, quality, economic efficiency and competitiveness on the basis of domestic farm products in tune with agriculture sector during the last several decades. Therefore, the Party and State should futher admend and issue appropriate regulations concerning the promotion of the biotech development and application in production and life, proper investments in human resource training programs, encouragement of scientific research activities in the field of biotechnology, and engagement of high-quality professionals who are dedicated in their pursuit of new and more valuable products in terms of both science and practical application.

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