7.13 Establishment of environmentally-adaptive-plant design systems for stable food supply in the age of climate change

Overview

To resolve the global food problems faced by Japan and other countries around the world, technologies for the development and the cultivation of agricultural crops that can adapt to climate change and other environmental changes must be established. In order to achieve these technologies, the knowledge in the area of basic plant science that is gained through model plant research in Japan must be linked to crop development and cultivation, and various biological data in plant science must be gathered and analyzed from new perspectives including technologies in engineering, information science and other different fields.

To this end, the Strategic Objective is focused on an information science approach to conduct an integrated analysis of genome, transcriptome, metabolome and other omics data accumulated in plant science, phoneme and other quantitative data obtained using state-of-the-art measurement technologies, and environmental factors and the like that have been quantified in numerical terms, in order to build prediction models for plant growth and environmental response. Subsequently, plants with the improved environmental adaptability that have been designed by using these prediction models will be developed, and demonstration cultivation in actual environments will be conducted, in order to achieve "environmentally-adaptive-plant design systems" which are based on "growth and environmental response prediction models"

This will make it possible to design, manufacture and cultivate crops able to grow under a variety of environmental conditions, thus ensuring a stable food supply.

Targets to Achieve

The Strategic Objective is to establish "environmentally-adaptive-plant design systems" which will make it possible to predict growth and environmental response of plants based on environmental conditions, various plant-related factors and other quantitative data, and to design, manufacture and cultivate plants with improved environmental adaptability. Specifically, we aim to achieve the following:

(1) Development of quantitative measurement technologies that can make a detailed characterization of growth, physiological state and environmental response of plants

(2) Identification of biological markers (biomarkers) for each target plant that can respond to fluctuations in phenotypic character

(3) Establishment of "growth and environmental response prediction models" that work by means of bioinformatics, integrating technologies in plant science and different fields such as engineering

(4) Design, manufacture and verification of plants with improved environmental adaptability based on the "growth and environmental response prediction models"

Future Vision of a Society to be looked at during the research promotion

The achievements of the targets listed under "3. Targets to achieve" contribute to we realize a society with the following characteristics..

- A society in which crop and plant varieties developed based on the predictions made using the "growth and environmental response prediction model" will make it possible to ensure stable food production even in areas unsuitable for the cultivation of existing crops, under increasing concern that rapid climate change may convert regions that are conducive to the cultivation of existing crops into regions that are unsuitable for the cultivation of those crops.
- A society in which it contributes to resolve food shortages due to population increase and environmental degradation that the "environmentally adaptive plant design system" based on the "growth and environmental response prediction model" and the crop improvement technologies, environmental monitoring technologies and integrated omics analysis technologies and the like developed by Japan will be provided to other countries in the form of a comprehensive agricultural technology package, andthat will enable stable crop cultivation even in

countries in which most of the land area is unsuitable for the cultivation of existing crops, and countries with reduced yields due to the effects of climate change.

Specific Research Examples

(1) Development of quantitative measurement technologies capable of detailed determination of plant growth, physiological state and environmental response

Improve phoneme analysis technologies that are capable of making quantitative determinations of plant phenotypes.. Also improve advanced sensing technologies and imaging technologies that can determine the precise physiological state of plants.

(2) Identification of biomarkers for individual plants that can respond to fluctuations in phenotypic character

Conduct research on the Identification of biological markers (biomarkers) that can respond to fluctuations in phenotypic character. Also conduct research on the accumulation of data on gene expression and metabolic changes that are linked to the phenotypic character of plants under various environmental conditions, such as outdoor settings and controlled environments.

(3) Establishment of a "plant growth and environmental response prediction model" through bioinformatics that integrates plant science with engineering and other technologies in different fields

Conduct research on the prediction of phenotypic character such as plant growth, flowering and so on in presumed environments will be conducted. Also conduct research on the prediction of responsiveness to environmental stress, genes that can improve tolerance, and prediction of related traits.

(4) Design, manufacture and verification of plants with improved environmental adaptability based on the "growth and environmental response prediction model."

Development and advance plant engineering technologies for the manufacture of plants that are designed to have improved environmental responsiveness based on the "growth and environmental response prediction model." The cultivation in outdoor settings and controlled environments of the plants designed and manufactured based on the "growth and environmental response prediction model" will be verified, and data on phenotypic character during the period of cultivation and changes in physiological state will be prepared and provided as feedback to the "plant growth and environmental response prediction model."

Domestic and Foreign Research Trends

(Trends in Japan)

Progress has been made in Japan in recent years in numerical analysis based on genome, transcriptome, metabolite and other types of "big data" in the field of plant science, and expression analysis that incorporates climate change, individual differences at the ecological level and so on is now the trend (Overview Report (of the specialist biology study team), FY 2013 Study of Trends in Academic Research, Japan Society for the Promotion of Science). But although the level of research in Japan in the field of plant science is extremely high and (as can be seen in the achievements in the International Rice Genome Sequencing Project) ranks with that being conducted in the United States and Europe, it has been reported that Japan lags behind the West in the application of such achievements, in terms of both the level of technical development and industrial technology capabilities (2009 International Comparison of Science and Technology Research and Development, Life Science Field, Center for Research and Development Strategy, Japan Science and Technology Agency).

(Trends Overseas)

In the United States, genetic analysis of the Arabidopsis (thaliana) has been pursued as part of the Plant Genome Initiative, and genetic analysis research of crops and vegetables has also been pursued in recent years. In Europe, the achievement of an integrated understanding through systems biology is being pursued based on certain specific systems, and in recent years research and development aimed at developing crops and vegetables has been conducted in the form of crop performance and improvement ("Environmental Response Mechanism and Breeding Technologies for Plants in the Field" 2009 Workshop Report, Center for Research and Development Strategy, Japan Science and Technology

Agency). Overseas, there has been a notable trend in which major biotechnology companies, which can develop its own unique DNA marker technologies and genetic analysis technologies, have absorbed midlevel seed and seedling manufacturers and expanded into the area of vegetable seed and seedling development. Furthermore, due to the widespread use of next-generation sequencers, the genome sequencing of non-model crops has been progressing rapidly in Europe, the United States and China (Panoramic View of the Life Science and Clinical Research Field (2013) 2nd Edition, Center for Research and Development Strategy, Japan Science and Technology Agency).

Background of Consideration

The following study was conducted based on the Expert Panel Report on the Envisioned State of Strategic Basic Research (June 27, 2014).

(Preparation of analytic materials regarding research trends in Japan and overseas using the Science Map and Database of Grants-in-Aid for Scientific Research)

We prepared analytic materials regarding research trends in Japan and overseas using information in the Science Map 2012 & 2010 (July 31, 2014 National Institute of Science and Technology Policy) and the Database of Grants-in-Aid for Scientific Research.

(Implementation of a questionnaire for specialists using analytical materials and preparation of notable research trends)

We conducted an opinion survey concerning future notable research trends for the specialists of the Center for Research and Development Strategy (Japan Science and Technology Agency) and experts participating in the S&T Experts Network operated by the Science and Technology Foresight Center (National Institute of Science and Technology Policy), using the analytical materials we had prepared. Then we analyzed the survey results and identified the "development of a system for the design of in silico plants to accelerate the elucidation of plant life phenomena" as a noteworthy research trend.

(Holding of workshops and preparation of Strategic Objectives)

We held a workshop to gather experts from industry and academia related to the noteworthy research trend of "development of a system for the design of in silico plants to accelerate the elucidation of plant life phenomena." We discussed particularly notable trends in Japan and overseas, the social and economic impacts of research and technology development and the future society to which they may give rise, and the targets that should be achieved during the research period. Then we prepared Strategic Objectives based on the discussions in the workshop.

Relevant Matters in Cabinet Decisions, etc.

The 4th Science and Technology Basic Plan (approved by the Cabinet on August 19, 2011)

III. 2. (1) ii)

To improve the food self-sufficiency rate, enhance food safety, and ensure a stable supply of water, the government will promote R&D concerning the production, distribution, and consumption of safe and quality food materials and products, and R&D concerning stable supplies of food and water, which will include the utilization of advanced technologies such as genetically modified organisms (GMO) and the adoption of industrial viewpoints.

III. 2. (5) i)

The government will promote R&D into nanotechnology and optical / quantum technologies that will lead to the development of advanced techniques for measurement and analysis, advanced information & communication technologies such as simulation and e-science, S&T that is cross-sectionally available in multiple areas such as mathematical science and system science technologies, and S&T for integrated areas.

Comprehensive Strategy on Science, Technology and Innovation 2014 (approved by the Cabinet on June 24, 2014)

Chapter 2, Section 1, IV. 3. (1) 1)

Considering such factors as the target market and technology competition in the world, while bridging between fundamental research and research for commercialization to achieve their mutual collaboration, this measure is aimed at strategically promoting the development of new breeding technology, etc., that realizes the provision of revolutionary products in the following fields: analysis of genomes and metabolites, development of an information base such as database creation; identification of useful genes, development of DNA markers, bioinformatics and engineering technology, and utilization of genome editing techniques.

Other

- For this Strategic Objective, the active participation of researchers in fields other than basic plant science — such as information science, engineering and agriculture — will be needed, and efforts to achieve substantive collaboration will be essential. It will be particularly important to ensure the participation and training of researchers in the field of bioinformatics, in which the lack of researchers has been pointed out as a problem. Moreover, in order to ensure the efficient use of research data and achievements in the life science field in Japan, maximum use must be made of the Japan Science and Technology Agency National Bioscience Database Center (JST-NBDC) and other resources.

In order to design projects that involve verification, we are hoping for the participation of institutions that are equipped with environments in which plants can be cultivated and managed under the same conditions as in actual crop cultivation environments. In addition, we also hope there will be organic collaboration with the Strategic Innovation Program (SIP) “Next-generation Agriculture, Forestry and Fisheries Industry Creation Technologies” and other exit strategies, and that the achievements of research conducted for this Strategic Objective will be deployed effectively.