ABSTRACT

The Japanese Cabinet adopted the 5th Science and Technology Basic Plan as a basic policy of science and technology innovation of five years from 2016 to 2020 and determined ‘Society 5.0’ as a future industrial structure and the ideal form of social system. Many of the economic and social issues that Society 5.0 aims to solve are nearly equal to the Sustainable Development Goals (SDGs). It was decided to promote the SDGs in an attempt to realize Society 5.0 as a nation and to collaborate further between private companies and government bodies including research institutes and higher education. The agricultural and food industry sector can realize Society 5.0 with Smart Food Value Chain of breeding, cultivation, harvest, storage, processing, distribution and consumption. The productivity of the entire food value chain should be improved, and wastes be reduced through the development of the latest technology and optimization of the whole food value chain. This can be done by analyzing diverse and huge data with AI, ICT etc. 2019 is an important year for applying the research and development results obtained so far to actual agricultural sites and realizing the Smart Food Value Chain in Japan.

Keywords: Society 5.0, Smart Food Value Chain (SFVC), Smart Breeding, Smart Production, Smart Processing, Smart Distribution, Smart Selling

INTRODUCTION

The 2030 Agenda for Sustainable Development was adopted by all United Nations Member States in September 2015 and the 17 Sustainable Development Goals (SDGs) were set for all countries - developed and developing - in a global partnership. The United Nations Member States have pledged that SDGs are universal goals that all countries will work with and leave no one behind on earth. With concerns over food supply pressure as the world's population grow, “zero hunger” was set as SDGs’ Goal 2. Sustainable agricultural production and stable supply of food are strongly required.

In many agricultural production sites of the world, sustainable and stable food supply are not always realized because of climate change, production instability due to pest damage and losses in harvesting, storage and distribution processes. In Japan, overproduction caused food loss on the value chain from storage, processing, transportation to consumption by lack of accurate demand prediction, and disposal of food due to business practices remain as major issues. In addition, Japan already arrived at a super-aging society where more than 25% of the population is over 65 years old. The population of agricultural labor is decreasing, and the entire food value chain, including processing, transportation, and sales, also faces the laborer shortage. Therefore, the agriculture and food industries need to improve productivity, improve efficiency, and reduce losses. Of course, these issues are common to all industries in Japan, not only just the agri-food industries.
The National Agriculture and Food Research Organization (NARO) is the core institution in Japan for research and development on agriculture and food under the Ministry of Agriculture, Forestry and Fisheries (MAFF). NARO is promoting national research and development in line with the policy of Society 5.0 that Japanese Cabinet presented to all research sector in “the 5th Science and Technology Basic Plan” in 2016. This paper introduces NARO’s contributions to realize Society 5.0 in agri-food industry.

OVERVIEW OF NARO

Organization

NARO has 3,300 full-time employees including 1,800 researchers and a budget of approximately 85 billion yen per year. Our research subjects cover all the needs from the agriculture to the food industry. For example, to improve productivity and quality of products, efficient and effective crop rotation for rice production, domestic fodder production for livestock feed, improvement of animal health, and development of high margin horticulture crops etc. are achieved. R&D for the farming infrastructure not only includes maintenance and improvement of irrigation and farmlands, but also enhancement of the living conditions and the multiple benefits of farming communities in line with rural development. R&D to elevate consumer confidence in food and farm products is focused on food safety, healthy eating, functional foods, quality enhancement and food processing. Most of researches are in collaboration with prefectural R&D institutes, universities, private companies and foreign research institutes. Our major outputs include patents and original papers as well as new variety registrations of agricultural products. Among the research institutions and universities in Japan, NARO is ranked as No. 1 in paper citations in agriculture, and No. 3 in botany and zoology.

The Headquarters of NARO is in Tsukuba, Ibaraki Prefecture, and research centers are located all over Japan from Hokkaido to Kyushu and Okinawa. The Research and Development component of NARO is performed by 5 regional agricultural research centers, 3 priority research centers, 7 specialized research institutes, and 3 research support centers (Anonymous 2018a, Kyuma 2018). In addition, the Agri-food Business Innovation Center promotes industry-academia cooperation, and the Bio-oriented Technology Research Advancement Institute plays a role as a funding agency.

Major research outcomes

The breeding research of various variety supports agriculture and food industry. Fuji apple (Sadamori et al. 1963) which is the worlds’ largest production variety and Shine Muscat grapes (Yamada et al. 2016) are just a few of the examples which have sold at the world market and brought high reputations in the world for NARO’s breeding technology (Figure 1).
Secondly, NARO also focuses on food processing, storage and distribution technology. A home bakery (bread baking machine in home use) which can bake gluten-free 100% rice flour breads (Yano et al. 2017). It controls fermentation and baking precisely and supports to enrich the quality of life of people who are allergic to wheat. NARO also develops and proves the validity on human beings of functional foods, beverages and agricultural fresh products, which created a domestic market following Japan’s functional foods policy and regulations (Anonymous 2015a, Anonymous 2015b).

The third subject NARO focuses on is biotechnology. After contributing to the international rice genome sequencing project (International Rice Genome Sequencing Project 2005), NARO is working on genome-based breeding of new varieties for higher yield and drought resistance (Takeuchi et al. 2016). Another major outcome is on genetically modified silkworms which are now kept in a farm and is considered as the first successful research output on the said subject in the world (Iizuka et al. 2013). These worms produce silk fibers containing green fluorescent protein. In the future, we aim to create new industries such as pharmaceutical production utilizing protein production ability of genetically modified silkworms.

The last research subject is on agriculture utilizing Information and Communication Technology: ICT. NARO has developed basic technologies of robot tractors that enable automatic travel and of an automatic remote-control system for water management in the paddy field with a smartphone (Anonymous 2018b). Fertilization can be optimized by using the “Yield combine harvester” which measures the mass and moisture content of the harvest and displays and records data of the harvest for each field. All these are at the mass-production stage and available for purchase from manufacturers.

DRASTIC CHANGE IN JAPAN’S SCIENCE AND TECHNOLOGY POLICY

The 5th Science and Technology Basic Plan and Society 5.0

Japan has many problems such as declining birth rate and aging population, energy and resource constraints, regional economics in decline, natural disaster risk. “The 5th Science and Technology Basic Plan” is the basic policy of Japan's science, technology and innovation for five years from 2016 to 2020 formulated by the Cabinet Office Council for Science, Technology and Innovation (CSTI) in January 2016 (Anonymous 2015c). The 5th Science and Technology Basic Plan defines the future vision of industrial structure and social system as “Super smart society: Society 5.0” (Anonymous 2015d). Many economic and social issues that Society 5.0 scopes on are in line with the United Nations' SDGs.

Society 5.0 is the concept that Japan propose to the world first. It follows the hunting society (Society 1.0), agricultural society (Society 2.0), industrial society (Society 3.0), and information society (Society 4.0). Society 5.0 is a human-centered society that utilizes ICT and digital technology that has developed dramatically in recent years and balances economic advancement with the resolution of social problems by a system that highly integrates cyber space and physical space (Figure 2). In the Science and Technology Basic Plan up to the 4th edition, only the solution of social problems by science and technology was stated as the objective, but from the 5th edition, “economic advancement” and "the resolution of social problems" should be balanced. As well as research organization and university, strong cooperation with the industry will be promoted all over the country to realize the Society 5.0.
NARO’s R&D policy

In Japan, the rapidly declining population and super aging society is leading towards the shrinkage of the domestic market and rural society. On the other hand, the large expansion of the overseas food market is predicted. Because the agri-food industry becomes the big business in future, it is thought that application of AI and ICT will be indispensable tools to solve many problems, and to make a success of business opportunity. NARO is focusing on the following six research subjects to realize the “Society 5.0 in agri-food industry,” (Anonymous 2018c) namely 1/Smart Agriculture, 2/Smart Breeding, 3/Smart Food Value Chain, 4/Biotechnology and Healthcare, 5/Fundamental Technologies (gene bank, agricultural data base such as soil, climate, etc.) and 6/Advanced Technologies (AI, big data analysis, robotics, etc.).

REALIZATION OF SMART FOOD VALUE CHAIN, SOCIETY 5.0 IN AGRI-FOOD INDUSTRY

Smart Food Value Chain

Figure 3 shows a conceptual diagram of Smart Food Value Chain. Establishment of the Smart Food Value Chain realizes Society 5.0 in the field of agriculture and food. The whole process from smart breeding, smart agriculture, smart distribution processing to consumption shall be connected. Data from each process in food value chain are accumulated in the Agricultural Data Collaboration Platform ‘WAGRI’. The accumulated data are analyzed by AI for optimization of the entire process for productivity improvement, reduction of waste, total cost cut, and technology matching.
As shown in Figure 4, the goal of Smart Food Value Chain is to realize an overall optimum system, not only to develop individual technologies for each process. It is necessary to accurately understand consumer needs and take a back casting approach in proceeding with overall research and development. However, it is also practical to consider the consistency of the process, before and after the individual research subject.

**Goal:** To realize Smart Food Value Chain as an overall optimum system, not just to develop individual technologies for each process on the food value chain.

**Objective:** To improve productivity, eliminate waste, reduce costs, improve quality, needs and seeds matching and optimize the entire food value chain.

**NARO's research areas to focus on:** Smart breeding, smart agriculture, smart distribution and processing, AI and ICT, Database establishment.

Figure 4. Strategy to realize the Smart Food Value Chain
The basic objectives of research and development of Smart Food Value Chain are to improve productivity, eliminate waste, reduce costs, improve quality, and matching of needs and seeds. In order to optimize the entire Smart Food Value Chain, standardization is also fundamental research subject. Information sharing and logistics can be smooth by using common rule in the management of the entire Smart Food Value Chain. One of the most basic examples of standardization is to unification of terminology used in quality evaluation.

In addition, the big and diverse data such as quality, quantity, needs, price, etc., provided from whole the food value chain should be shared across all stakeholders and analyzed using AI and ICT. It is also essential to optimize the entire food value chain.

**Recent Research Products on Smart Food Value Chain**

NARO uses genome editing technology to develop rice with increased number of rice grains and size of rice grain (Komatsu 2019) and conducts experimental cultivation in an outdoor isolation field.

NARO aims to improve profitability based on expansion of planted area and reduction of labor cost by using a robot tractor that one operator can operate multiple machines. It has been proven that working time in the field can be reduced by about 40% when one robot operator operates two robot tractors (Noguchi 2012). NARO is now developing a system with which one operator can operate five robot tractors.

It is very important to guarantee the quality of agricultural products during the transportation. NARO has developed technology to predict future quality nondestructively using near infrared spectrum. This technology can predict, for example, the deterioration of apple (Matsubara et al. 2017) or the ripeness of peach before one month. It is expected to guarantee product quality and reduce waste.

**Figure 5. Minimum heating process using electrical energy**

1) Minimum heating process (MHP) technology allows to sterilize foods by electric power in short time.
2) After MHP, food keeps its fresh taste, texture, flavor, color and nutrition.
3) The technology contributes to food safety and longer shelf life.
4) MHP allows to reduce salt and sugar added for food preservation.

NARO has developed a minimum heating process using electrical energy (Figure 5). This process can greatly reduce the processing time compared to conventional heating methods (Kanafusa et al. 2018). One of the main features is that the fresh taste and aroma of various agricultural products can remain after processing. The amount of salts and sugars added as preservatives can be also reduced.
The realization of "Society 5.0" in the field of agriculture and food requires strengthened agricultural information research using AI and data linkage base. Figure 6 shows the Agricultural Data Collaboration Platform named WAGRI which is established in August 2017. The term WAGRI is a coined word combining WA (a Japanese word meaning “harmony”) and AGRI (agriculture). By building a platform that provides data such as weather, soil, satellite imagery, growth etc., NARO creates a platform where farmers can utilize data to try further improvement of productivity and profitability. These agricultural data are analyzed by AI, and then used to optimize a series of processes from breeding, agricultural production, processing, distribution to consumption. In the future, it is expected to contribute to the entire Smart Food Value Chain by collecting and linking market information and consumer needs.

**Figure 6. Agricultural data collaboration platform named WAGRI**

1) WAGRI aims for agri-food data linkage and sharing.
2) The data, accessible by agri-food sector, solve the problems associated with agricultural ICT and encourage productivity improvement.
3) AI technology is used to optimize the entire process of agri-food industries.

**Perspectives and challenges to realize the Smart Food Value Chain**

Research and development based on the Cross-ministerial Strategic Innovation Promotion Program (SIP) started in 2013 (Anonymous 2017). SIP is a cross-cutting program across government agencies and fields. The CSTI examines and determines the research subjects to which the budget is to be allocated among the existing R&D programs of governmental agencies. Another feature of SIP is to consider the reform of regulations and systems scoping from the basic research to commercialization. Phase I of SIP (2013-2018) advanced the somatization of agricultural production by development of robotic agricultural machines such as the robot tractor and development of technology for yield prediction of large-scale greenhouses.

1) Implementation to the farms

The “On-Farm Demonstration Trails of Smart Agriculture” project was launched at 69 locations nationwide for two years from 2019 aiming to apply the research results developed in SIP I to actual production sites. Technology was mainly developed for large-scale rice cultivation, upland farming, and relatively good field conditions in SIP I. However, actual farms vary in field conditions such as location, land shape, soil, etc., resulting in the problem that machineries, equipment and facilities become too pricy. So, this project is purposed to accelerate the social implementation of the technology developed in SIP I by applying it to actual farms such as paddy fields, upland fields and greenhouses under various conditions, extracting and solving problems, tackling difficult conditions and reducing cost.
In addition, SIP II was started with a five-year plan from 2019. The objectives of SIP II is to widen the variety of agricultural products, to include upland farming and greenhouse cultivation, and to promote smart production to small and medium-sized farms.

2) Development of Smart Food Value Chain

Phase II SIP (2019-2023) are in progress from the R&D into implementation to the farms, expansion of various cultivars and application to smaller sized farms which are majority in Japan. SIP II was also launched to realize the entire Smart Food Value Chain. The projects include building the Smart Food Value Chain model for several items by streamlining distribution process from production to consumer. All information from the entire Smart Food Value Chain including consumer needs is accumulated and analyzed. NARO has also started a project for the construction of regional Smart Food Value Chain model in Kyushu-Okinawa Economic Region. These projects are important to demonstrate possibility of Smart Food Value Chain, and further progress is expected.

CONCLUSION

In order to realize Society 5.0, Japanese industry, academia and government have switched to new direction toward research and development in the field of agriculture and food. To implement Society 5.0 in agri-food filed is to realize the Smart Food Value Chain. NARO focuses to achieve the Smart Food Value Chain strategically. The Smart Food Value Chain cannot be realized in Japan alone in future. NARO can contribute to the reduction of losses and efficient and stable supply of food in Asia and the world. NARO actively promotes cooperation with overseas organizations and plans to establish overseas bases by the spring of 2020. NARO’s R&D will contribute to the development of the Smart Food Value Chain by building strong partnerships between agriculture and food research institutions in Asian countries.

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