【Moonshot Goal 5】

"Creation of the Industry That Enables Sustainable Global Food Supply
by Exploiting Unused Biological Resources by 2050"
Research and Development Conception

March 2020
Ministry of Agriculture, Forestry and Fisheries

１． Moonshot Goal

Among Moonshot goals (Decision on Council for Science, Technology and Innovation, January 23rd, 2020), we promote research and development to achieve the goal shown below.

<Moonshot goal>

"Creation of the industry that enables sustainable global food supply by exploiting unused biological resources by 2050"

(Targets)

〇Technical development of the circular food production systems by biological measures, e.g. utilizing microbes and insects, by 2050.

〇Development of technical solutions for eliminating food loss and waste and for achieving both healthy life and sustainable food consumption by 2050.

〇Evaluation of the technical achievements and discussion on the ethical, legal and social implications (ELSI) matters will be done by 2030, for global spread of the technology by 2050.

(Research promotion organization: Bio-oriented Technology Research Advancement Institution)

２． Necessity of setting the Moonshot goal

To date, we have been developing farmland, woodlands and oceans on the earth, and achieved increases in food production making full use of various technologies according to the growth rate of the world population. However, it has also brought about destruction of the natural environment and overhunting of natural resources causing various problems including degradation of soil caused by excessive use of chemical fertilizers and agricultural chemicals, and contamination of rivers and groundwater.

In recent years, the global warming due to greenhouse gases has intensified, and the reduction of such gases has become an urgent task. Globally, a quarter of the total emission of greenhouse gases including nitrous oxide (N_2O) and methane is caused by the agricultural and forestry industries, and the use of land.

It is estimated that the world population in the year 2050 will increase by a factor of 1.3 (relative to 2010). With the increase in demand for grain as food for livestock in medium income countries, it is anticipated that the demand for food will greatly increase by a factor of 1.7. It is anticipated that there could be a serious shortage of food worldwide in 30 years time, thus it is necessary to increase food production furthermore in the future. However, although organic substances, which constitute food, circulate as agricultural products, foodstuffs, excretory products, soil materials and so on, the circulation collapses under the current methods which only focus on production efficiency, and this exert bad influence on global environment including climate change and obstruction of sustainable food supply. To satisfy both increasing food production and conserving global environment, we should revise current food production methods radically.

On the other hand, in some organizations including microorganisms and insects, there should be a large number of unutilized biofunctions. It is important to elucidate the unexploited “knowledge” and to make full use of functions of nature and organisms for creating new socio-economic activity systems.

Therefore, in order to ensure our food sustainably in the future and to achieve increases in food production according to the growth of the world population, we must develop the circular food production systems by biological measures, e.g. utilizing microbes and insects.

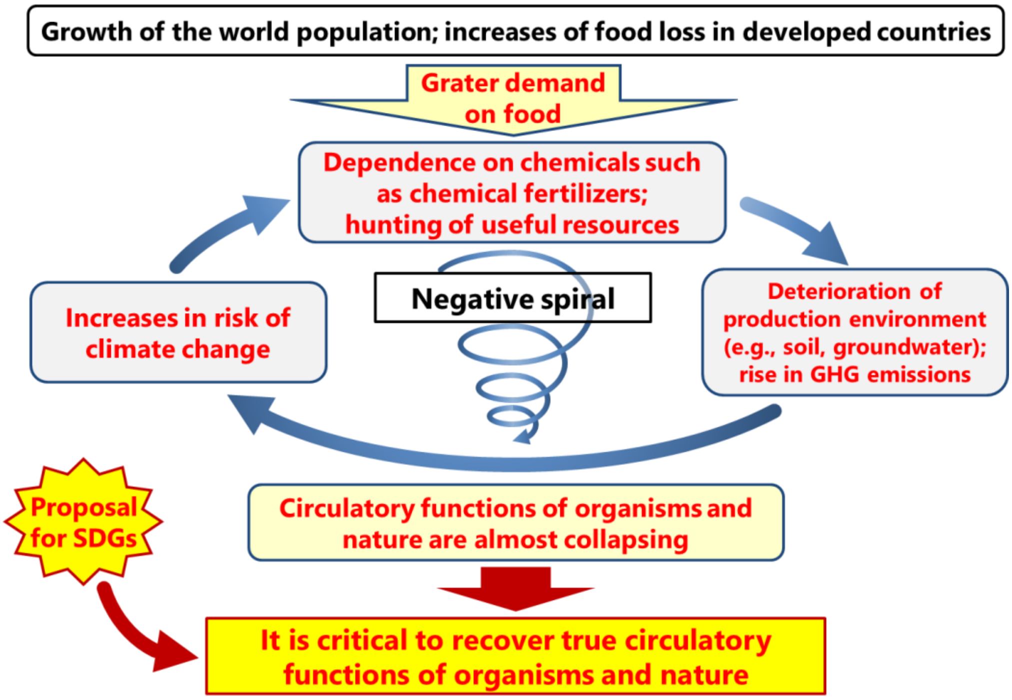

Figure 1. Anticipated food supply issues in 2050

In addition, it is necessary for us to reconsider consumer behavior in future. Currently, social problems, such as the waste of large amount of food, and increases in obesity and lifestyle-related diseases are mainly occurring in developed countries, including Japan.

Therefore, it is necessary to take challenging actions that will expand globally through the creation of new solutions for eliminating food loss and waste and for achieving both healthy life and sustainable food consumption.

Furthermore, the United Nations Sustainable Development Goals promote the importance of:

(1) Conserving the ecosystem, increasing the capacity to adapt to climate fluctuations, and promoting sustainable agriculture (Goal 2)

(2) Expanding afforestation on a global scale, and promoting conservation of natural ecosystems, including conservation of biodiversity (Goal 15)

(3) Conserving oceans and ocean resources, and utilizing them in a sustainable manner (Goal 14)

(4) Reducing food waste and food losses, and ensuring sustainable forms of production and consumption (Goal 12),

and today international cooperative activities are starting.

In view of the above, there is an urgent necessity to bring together the wisdom of researchers and businesspeople throughout the world to promote challenging research and development based on the goal "Creation of the industry that enables sustainable global food supply by exploiting unused biological resources by 2050", in order to satisfy both the anticipated growth of the world population and conservation of global environment.

３． Direction of Research and Development

Based on the discussion on Moonshot International Symposium (December 17th and 18th, 2019) and so on, the direction of research and development at the moment is as follows.

（１） The Target Areas of Challenging Research and Development

In order to achieve a sustainable increase in food production while responding to climate change that is expected in the future, it is necessary to remarkably improve the environmental adaptability of crop plants. In order to maintain the food production, it is also required to drastically reduce the dependence on water and artificial materials, to prevent adverse effects on the global environment, striving for conservation of biodiversity. Therefore, it is essential to elucidate and utilize the unexploited biofunctions such as insects, soil microorganisms, microorganisms in human body, and plants for creating the circular food production systems.

With increasing food production, it is also significant to consume food effectively for eliminating food loss and waste, thus it is required to make an innovation in our consumption behavior. While we are currently facing social problems, such as environmental deterioration by the waste of large amount of food, and the increase in obesity and lifestyle-related diseases which are mainly occurring in developed countries, the starvation problem has not yet been solved. Therefore, it is preferable to develop new solutions which will reduce food loss and waste, and reliably deliver the necessary amount of food to the people who require it.

In view of the above, it is necessary to establish the food production and consumption systems that achieving both food supply expansion and global environment conservation by exploiting unused biological resources, however, at this moment in time it is too difficult to realize it, and research and development in elucidation and utilization of biofunctions is far from social implementation. Therefore, we suppose to set "satisfying both increasing food production and conserving global environment" as the area for promoting challenging research and development in Moonshot Research & Development

Program.

（２）Research Subjects Toward Moonshot Goal

In Moonshot Research & Development Program, we invite challenging research and development in the above target area both within and outside Japan.

In the program, we implement the challenging subjects which conduct technical development contributing achievement of Moonshot goal. In terms of technical approach, we adopt subjects based on scientific verification, and implement them with setting Stage Gate. In addition, in order to adopt the most efficient and effective methods, the latest scientific trends are reviewed, and they are reflected to the research and development.

From the perspective of smooth social implementation of the research results, the research system must be examined so that researchers with various backgrounds can participate in the discussion about ethical, legal and social issues (ELSI) related to the program.

<Food Production Systems Achieving Both Food Supply Expansion and Global Environment Conservation>

Supposed examples of research and development are described below.

- Elucidating the whole mechanism of “resilience” of wild species that can resist poor surroundings
- Creating new lineage of plants with designed functions by reconstructing plant genomes from nothing
- Making full use of soil nutrients and developing technology to reduce emission of greenhouse gases by total control of the soil microbial environment
- Developing complete pest control technology unaffecting ecosystem
- Creating plants and alga with high ability to absorb carbon dioxide and developing circulation system of organic substance by utilizing them

<Food Consumption Systems Realizing Zero Food-loss and Waste>

Supposed examples of research and development are described below.

- Developing systems that can match and deliver all supply and demand needs in real-time in cyberspace
- Developing super-long food conservation technology by biological measures
- Developing technology that converts surplus agricultural products and household food residue into health- and environment-conscious edible food, e.g. development

of 3D food printing and cocking systems that reusing these residues by grinding and separating

- Developing technology that converts food and land residues into food and/or feed for aquaculture by biological measures

（３） Direction of Research and Development Toward Moonshot Goal

○2030 (Output Goals)

<Food Production Systems Achieving Both Food Supply Expansion and Global Environment Conservation>

Develop and evaluate the prototype of “the circular food production systems by biological measures”.

<Food Consumption Systems Realizing Zero Food-loss and Waste>

Develop and evaluate the prototype of “the technical solutions for achieving both healthy life and sustainable food consumption”.

○2050 (Outcome Goal)

“Creation of the industry that enables sustainable global food supply by exploiting unused biological resources” means that both “the circular food production systems by biological measures” and “the technical solutions for achieving both healthy life and sustainable food consumption” spread globally. The image of 2050 (outcome goal) is shown in Figure 2.

For achieving 2050 (outcome goal), i.e. establishing both “the circular food production systems by biological measures” and “the technical solutions for achieving both healthy life and sustainable food consumption”, we need enough time to establish evaluation fields, to solve technical problems at each stage, and to spread products and systems. In addition to research and development, discussion of discussion on the ethical, legal and social implications (ELSI) matters is also necessary. Thus, the goal by 2030 is establishment of prototypic technology.

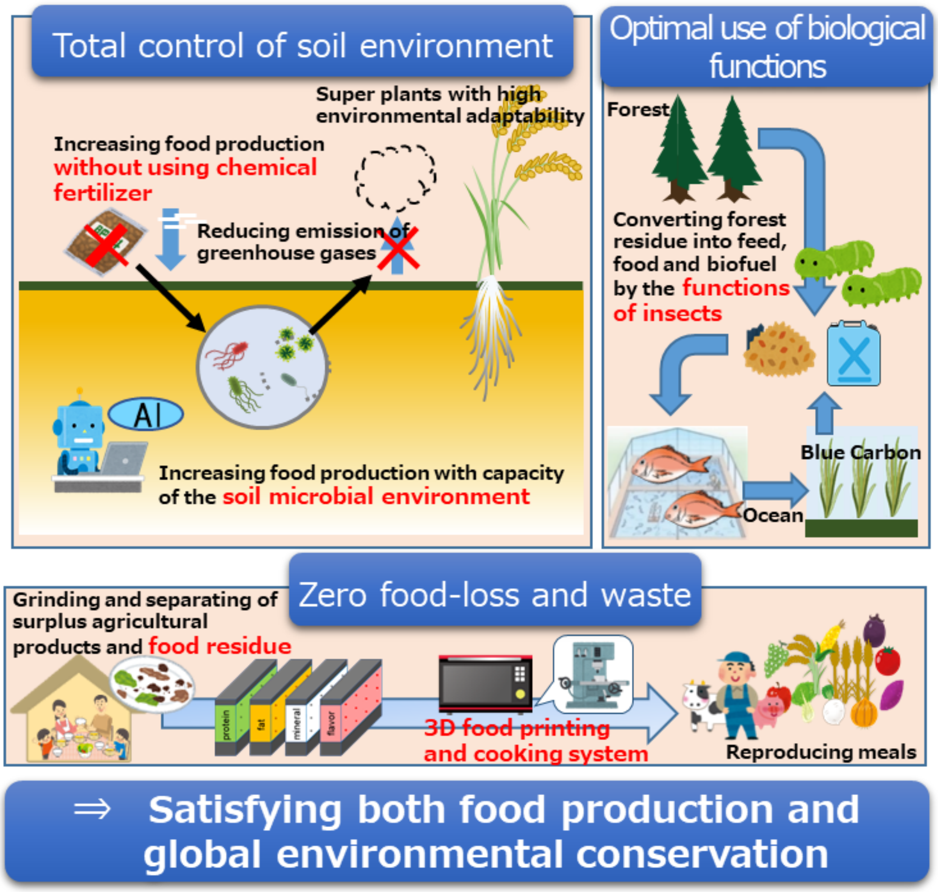

Figure 2. The image of 2050 (outcome goal)

＜Reference：Analysis Toward Moonshot Goal＞

According to Initiative Report at Moonshot International Symposium (December 17th and 18th, 2019) and so on, analysis toward Moonshot goal is as follows.

（１）Technology and Research Trends Related to the Food Production System Achieving Both Food Supply Expansion and Global Environment Conservation

Studies on the interaction between plants and soil microorganisms (Figure 3, gray dots) and symbiosis between plants and microorganisms (green dots) are ongoing but started to increase from 2012. There has been a slight increase in research on soil microorganisms and greenhouse gases since 2015, but the number of studies is still small (yellow dots). Studies on genome editing in microorganisms have been increasing since 2013 (orange dots), but when the studies are limited to soil microorganisms, the number is extremely small (11 cases, data not shown). Therefore, studies on the design and modification of soil microorganisms could be regarded as a future field of research.

However, the number of studies on genome editing in plants has increased rapidly since 2013 (blue dots). This coincides with the time when CRISPR/Cas9 began to be applied to plants. Research results are expected on topics including the development of basic technology for genome editing and crop creation using genome breeding technology. In contrast, there are still few studies on breeding using AI (39 cases, light blue), which shows that this research is in its infancy. However, the number of cases began to increase in 2019 and research in this field is expected to increase rapidly in the future.

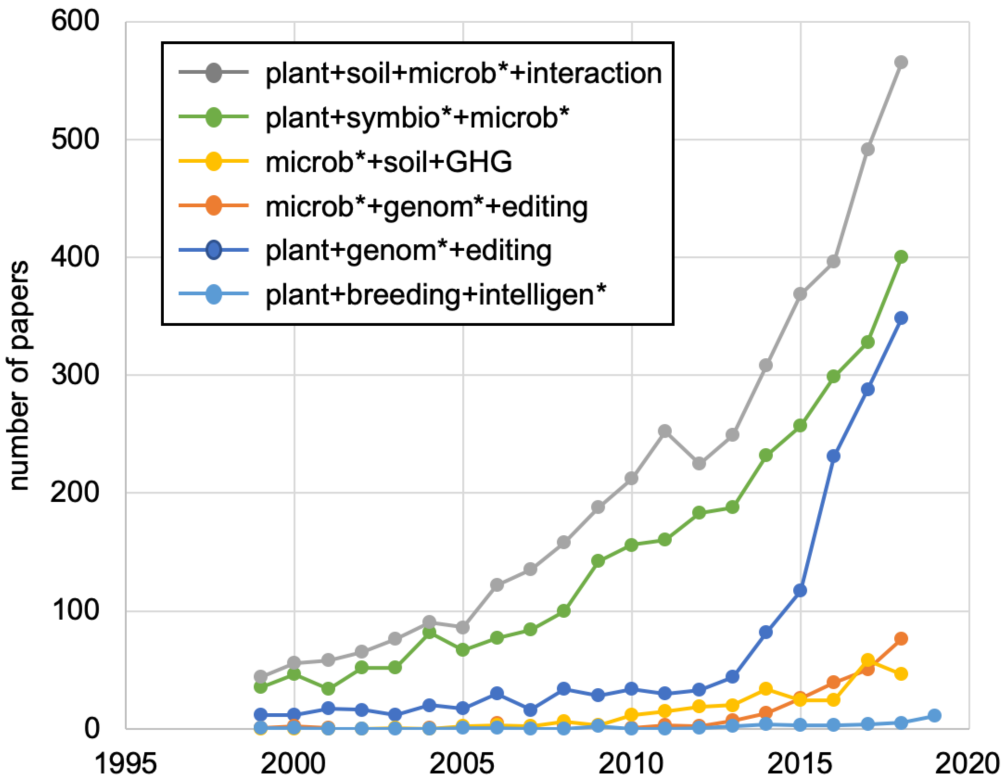

Figure 3. Research trends on breeding and soil microorganisms in Japan and overseas from 1999 to 2019 (Clarivate Analytics, Web of Science)

An overview of the research trends on the development of pest control methods, shows that the two predominant fields with the largest number of papers to date are chemical control (chemical pesticides) and biological control (use of natural enemies of pests) (Figure 4-A). The next largest fields of research are related to physical control, cultural control, resistant varieties, symbiotic microorganisms, and sterile insect techniques. Of these, the two areas in which the number of research cases has increased significantly over the past five years are the use of symbiotic microorganisms and the release of infertile insects (Figure 4-B, purple and light blue dots). However, the number of studies on pest control using genome editing has increased rapidly in the last three years and research using drones and AI is also starting to increase. Research in these fields is expected to increase further in the future (Figure 4-C).

In the field of life sciences, omics analysis at the single cell level has become possible over the past few years, and imaging technology has made significant progress. Furthermore, the accuracy of genome editing technology has improved, and it is being developed for application in medical and food industries. Information and communication technologies (ICTs) such as measurement technology and AI machine learning are steadily making inroads into life sciences through automation and scale-up. In addition, understanding of life phenomena is progressing through a new “data-driven” approach to discover laws from a large number of phenomena occurring in life. On the contrary, with the progress of AI, genome editing, synthetic biology, and so on, ELSI are posited as important challenges in the promotion of science and technology (R&D overview report, integrated version 2019).

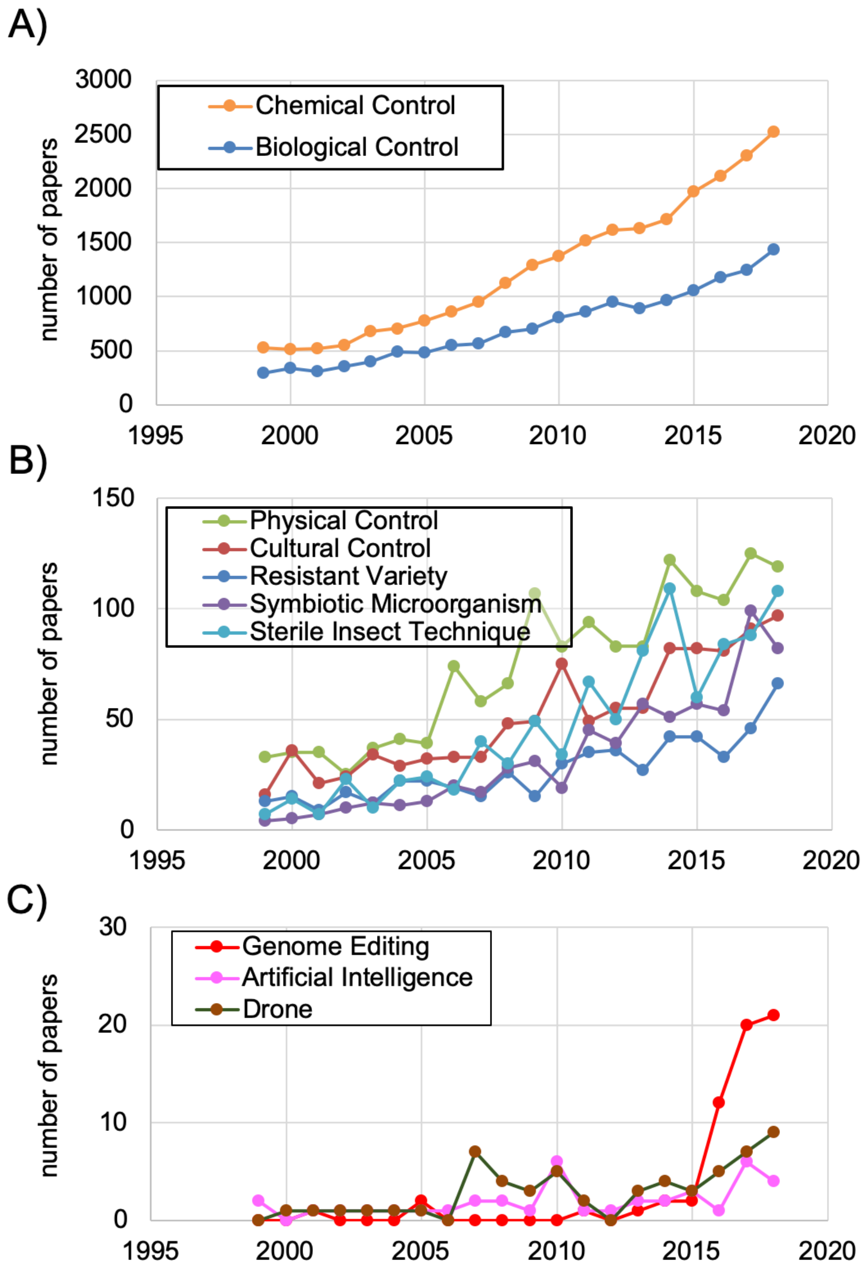

Figure 4. Research trends on pest control in Japan and overseas from 1999 to 2018 (Clarivate Analytics, Web of Science)

（２） Technology and Research Trends Related to Food Consumption System for Achieving Zero Food Loss

Research into food losses and waste has been on the increase (Figure 5), particularly in the last five years. While much of the literature from around 2000 is in the fields of zoology, sociology, nutritional science, and oceanography, research in the fields of transportation science technology, transportation, and telecommunications has seen growth in recent years.

This indicates growing momentum toward actively managing supply-demand mismatches in food from the stages of production through consumption (i.e., in food supply chains), which are largely responsible for food losses and waste.

To reduce food losses and waste, it may be useful to link food supply chains to AI-based information networks, particularly IoT and ICT, which have progressed rapidly in recent years. However, research in this field has still received little attention, with only three studies in 2014 and eleven in 2018. The key characteristic of fresh foods is the fact that they deteriorate in quality or decay during the course of the distribution process after harvest, and eventually become worthless. Therefore, future application of IoT to food distribution should take into consideration not only information about the quantity of food, but also about its quality (such as quality changes over time).

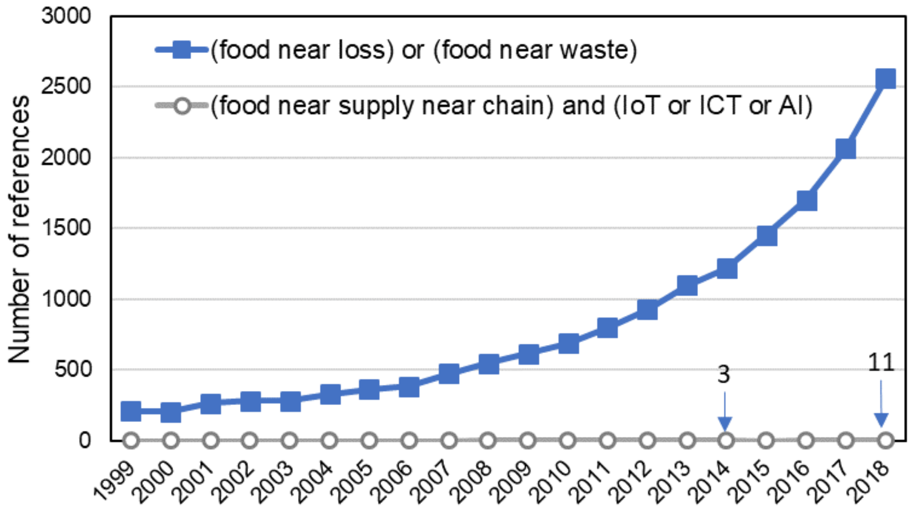

Figure 5 Research trends in food losses and waste, and food supply chains (Clarivate Analytics, Web of Science)

When considering the active use of food losses and waste, one solution is to convert them into energy or materials. Among the existing research projects on food losses and waste, studies addressing these topics account for approximately 24% and 14%, respectively, suggesting a relatively large interest (Figure 6). Methods of converting food to energy or materials include smart use of biofunctions, in addition to chemical and physical methods. Although related research has been conducted to date, however, it accounts for only about one-seventh of the research into energy and materials conversion overall.

Meanwhile, recycling of food losses and waste has been the subject of highly successful projects such as one on fermented liquid feeding (Sasaki et al., 2011), but such studies represent as little as 5% of all research projects on food losses and waste. This area of research is far from being advanced due to issues of social acceptance and technical difficulties.

Another potential approach to recycling would be to take advantage of Japan's ocean resources to explore the possibility of aquaculture applications for food losses and waste; however, little attention has been paid to this area so far.

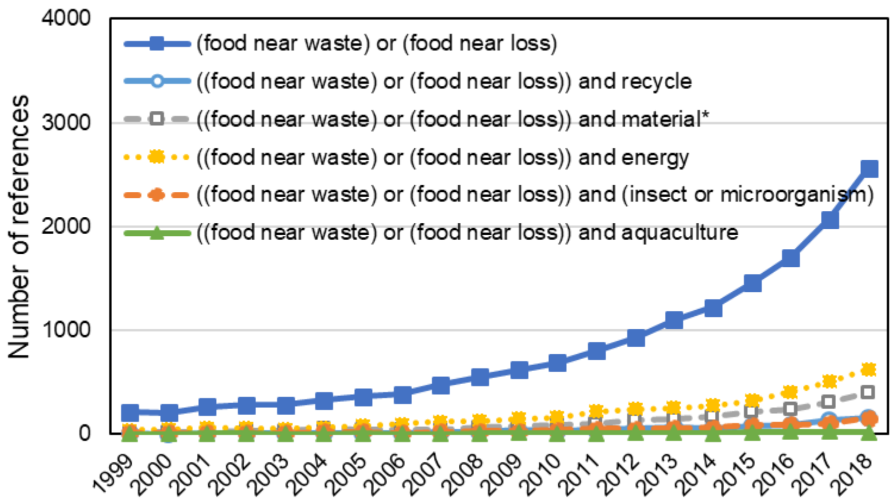

Figure 6. Research trends in food losses and waste focusing on recycling, materials/energy conversion, insects/microorganisms, and aquafarming (Clarivate Analytics, Web of Science)

One means of reducing food loss, waste, or disposal is the method of "reprocessing" into foods with excellent nutritional benefits and taste by using edible resources such as surplus agricultural products, non-standard products, and by-products as food materials. In recent years, the development of 3D printing technology has been remarkable (Figure 7). Such 3D printing technology can produce small quantities as well as a large number of individual items and is thus considered a promising means of enabling individuals to select various foods in the food field. However, there are actually few studies on the use of 3D printers in the food field (Figure 7 orange) as opposed to the industrial field. In addition, the materials used in the food field are limited to ingredients that are easy to put into the printer.

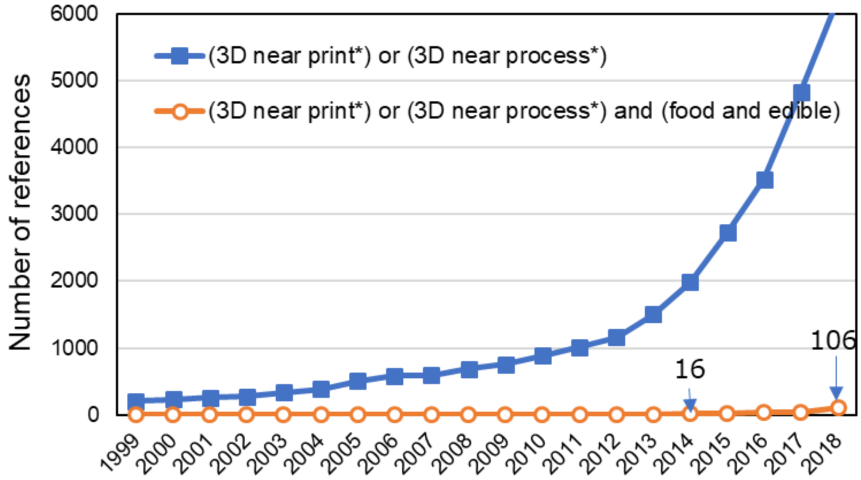

Figure 7. Research trends in food losses and waste, and food supply chains (Clarivate Analytics, Web of Science)