NARO International Peer Review 2024
Review Report

I. Peer Review of Research Programs

Program 1: "AI and agriculture" smart-production technologies

The rating is: **S –** to maximize the results of R&D, the creation of particularly noteworthy results or the expectation of excellent results in the future are recognized**.**

Overall Comments from the Peer Reviewers

This research field aims to develop and expand WAGRI, which is the cooperative foundation of agricultural data. It also aims to optimize the production system by utilizing AI. It aims at social change through innovation in order to integrate different data streams and make them practical for end users. Integration of differing disciplines and forecasting using AI are very new, ambitious, and highly visionary. In particular, it is a timely and appropriate initiative in the current situation where the number of agricultural leaders in Japan is decreasing.

The following are recommended for future direction.

i) It is essential to understand user requirements and create seamless, easy-to-use and fieldable products, while establishing metrics for success to assess utilization and acceptance. Additionally, continuous evaluation of data quality and the development of a feedback loop between scientists and developers are crucial for ongoing program implementation and improvement.

ii) To maximize the ratio of output to input, it will be important to consider the implementation of methods into practice when the research is planned.

iii) As further scientific extension of these research lines, AI could be used for planning crop rotation, modelling the population dynamics of pests and diseases and planning area-wide growing systems. A further important field of activity and extending current research lines could be the use of the developed methods in 3D cultures such as grapes of fruit trees.

iv) So far, the program is focused on crop production rather than on animal husbandry. A better integration of livestock production data and technologies is recommended for the next stages of development.

v) In terms of methods, developing standardized ontologies is a first pre-requisite to ensure consistency. However, if not already done a full review and standardization of the ontologies used by the WAGRI platform would reduce risks of confusion and would enhance the traceability of the data. The AI will only be as good as the data used for training, therefore a quality assurance and control mechanism needs to be developed for all data streams supporting the AI training.

vi) The platform design should facilitate the provision of anonymized data by farmers for further improving the AI. Farmers contributing with their own farm data may need to receive incentives to do so.

vii) Sociological and economic studies would be useful to understand farmers motivations and their willingness to pay for the services provided. Co-designing these new services with cooperatives, with advisers, farmers and other users is needed as it will presumably enhance large scale adoption.

viii) Future developments will require thorough quality assessments and an in-depth understanding of the needs expressed by farmers. Since many companies are partnering with the WAGRI platform, it would be important to inter-compare and to improve the services they are providing in order to ensure that the platform and all of its services have high quality standards. This would greatly help in developing the trust of users for this AI supported platform.

NARO Response to the Comments of the Reviewers

We express our gratitude for the many valuable comments. Below we describe the correspondence in each of the paragraphs.

i) This time, we introduced data aggregation for disease and pest diagnosis. It's crucial to continuously improve quality. We are always thinking about how to use feedback from demonstration experiments and evaluations after dissemination to enhance the product, and we are advancing our technological development accordingly.

ii) It is important to consider the results obtained from development technology and continue with research and development. During the planning stage, we will evaluate whether the output of development technologies, including maintenance costs, balances the input costs. We will also consider costs through technological innovation after the service is deployed.

iii) We agree with your perspective as we are also considering the future development of AI technology. Since fruit-related AI is not widely used in the Japanese agricultural market, we will focus on this area in the future.

iv) Regarding livestock production, we have started to see results through imaging of livestock excreta. However, there are almost no APIs installed in WAGRI. Given the large market for livestock production in the agricultural sector, we will focus our efforts here in the future.

v) Ontology development is still in its early stages, including breeding data. Currently, we are focusing on collecting high-quality data. Since standardization is still a future consideration, we will proceed with an ontology by referring to existing examples.

vi) We handle information about producers with care. As more farmers use information systems, we strongly feel the need for incentives that producers would want to use. It is important to explain the benefits of these systems, such as increased revenues.

vii) We believe it is important to build an information ecosystem with regional players to implement future development technologies. When designing collaboratively, we will consider proposing a system that benefits all stakeholders.

viii) Regarding WAGRI such as cooperation on generative AI, we are considering how to improve the service quality and whether there are additional services beyond the current API provision. We are reviewing WAGRI's roles to ensure it becomes a trusted and reliable platform. We aim to operate under a new system in fiscal 2026.

Program 2: Utilization and conservation of genetic resources

The rating is: **S –** to maximize the results of R&D, the creation of particularly noteworthy results or the expectation of excellent results in the future are recognized**.**

Overall Comments from the Peer Reviewers

The Genebank Project at NARO collects, conserves, and characterizes genetic resources, and plays a key role in Japanese sustainable food systems. This project pursues two goals: (1) stable management of genetic resources and (2) creation of new value for genetic resources. Although several hundred thousand genetic resources have been preserved for a long time, the progress of research on the cryopreservation of silkworms and plant tissues, in particular, is noteworthy. They are distributed on request and have important implications in domestic and international breeding programs.

The following are recommended for future direction.

i) Continue establishing partnerships with overseas gene banks to standardize technologies and practices, thereby enhancing the global exchange and utilization of genetic resources. Also, further research should be conducted into improving cryopreservation methods to enhance the viability and longevity of a broader range of genetic resources, including additional plant and microorganism species.

ii) It is further recommended to use automated high throughput sequencing methods for characterization and genotyping the entries. By strengthening the cooperation and interaction with other NARO institutes, such as Research Center for Agricultural Information Technology (RCAIT), novel technologies, such as AI, could be integrated into the phenotyping of the entries.

iii) Efforts are often made to define core collections of major crop species and to characterize in depth (through phenotyping and genotyping) the traits and the genetic structure of such core collections. This approach has started (e.g. for eggplants, and upland rice) but could be further developed in close collaboration with the crop breeding division at NARO and with other gene banks. It is likely to improve (and to some extent summarize) the description of key genetic resources used in Japan.

iv) The strategy of genetic resources valorization could be further used to market products of controlled origin with a premium price, as well as to market traditional organic crops. Participatory breeding by farmer's networks could also contribute to the dissemination and further improvement of local genetic resources conserved by the gene bank.

v) A broader effort could be launched to study across the accessions of some major crops, specific traits for climate change adaptation (e.g. thermotolerance, salt tolerance, tolerance to droughts and to floods, flowering time, etc.). This would also imply more systematic exchanges of genetic resources with other gene banks. For instance, to collect a germplasm adapted to climatic conditions present elsewhere and expected in Japan by 2050. Studies of the pan-genome of major crop species may also help in understanding the climate adaptation of major crops and could be used to detect traits conferring an increased resilience changes in climatic conditions.

NARO Response to the Comments of the Reviewers

i) In 2024, we started research aimed at enhancing the survival rate and lifespan of various genetic resources. This research is part of the Mid-Term Plan of the Research Center of Genetic Resources at NARO (NCGR), which will begin in 2026. Since 2023, we have been actively improving cryopreservation methods and expanding the range of genetic resources covered by these improvements. We will continue these efforts in the future.

ii) NCGR uses next-generation sequencing technology to perform reference genome sequencing of conserved genetic resources for each crop species in the Genebank. Currently, clarification of the characterization of these genetic resources is still stuck using conventional surveys. In the future, we plan to collaborate with RCAIT and other organizations to conduct phenotypic analysis of genetic resources using new techniques such as AI.

iii) NCGR is collaborating with the Institute of Vegetable and Floriculture Science to develop core collections of crops like cucumber, eggplant, and melon. Additionally, we are promoting the sharing of genetic resource information with domestic research institutes that have genetic resources, and we are trying to utilize genetic resource information that NARO does not possess. In the future, we will further promote the sharing of information on agriculture-related genetic resources within the country and strive to secure easily accessible genetic resources.

iv) In NARO's Genebank, we distribute genetic resources to users for research and educational purposes. This means they can be used for developing new crops, such as through breeding, but using genetic resources in their natural form for commercial purposes is not allowed. Therefore, NCGR has been promoting the use of genetic resources as breeding materials by highlighting the characteristics that add high value to these resources. We will continue to actively promote these activities. We believe that participatory breeding through farmers' networks is a useful way to conserve local genetic resources and propagate genetic resources in the Genebank. We would like to consider this approach in the future.

v) The Genebank accepts a large number of genetic resources from overseas and continues to collect them through bilateral joint research. In 2023, we began exchanging genetic resources with Germany, the United States, Taiwan, and other organizations that conserve genetic resources. We are working to expand the diversity of genetic resources through these exchanges. Genetic resources in the Genebank are distributed to domestic and international research institutes to facilitate pan-genome analysis of major crop species, aiming to elucidate, for example, climate change adaptation characteristics. In the future, we will continue to expand and distribute diverse genetic resources to promote research and breeding of varieties that address issues such as climate change adaptation.

Program 3: Innovative solutions for mitigating agricultural greenhouse gas emissions

The rating is: **A –** to maximize the results of R&D, the creation of noteworthy results or the expectation of good results in the future is recognized.

Overall Comments from the Peer Reviewers

The program aims to contribute to the goal of reducing greenhouse gas (GHG) emissions from agriculture, forestry, and fisheries, and eliminating CO_2 emissions by 2050, in accordance with the MIDORI strategy for sustainable food systems. Specifically, it is to develop techniques to reduce GHG emissions from livestock, paddy fields, and soil and to improve productivity and environmental conservation while sequestering carbon in the soil. These include techniques for measuring methane emissions from cattle using the sniffer method, reducing CH_4 emissions by extending the duration of drying in paddy fields, reducing N_2O emissions through the use of optimized nitrogen, and developing tools for comprehensive greenhouse gas (GHG) monitoring and visualization, as well as the use of biochar.

The following are recommended for future direction.

i) Further refinement of the sniffer method and other measurement technologies is recommended to improve the accuracy and ease of use for assessing CH_4 and N_2O emissions across in diverse agricultural settings.

ii) Research on the synergistic effects of combining multiple GHG reduction strategies, to optimize both emissions reductions and agricultural productivity is recommended. Further, continue to study the utilization of biochar and its impact towards carbon sequestration in agricultural applications is also recommended.

iii) Conducting long-term studies to evaluate the ecological and economic impacts of implemented GHG reduction technologies, focusing on trade-offs between emissions reduction, biodiversity conservation, and soil health is recommended.

iv) The aim of NARO is to develop technologies to reduce emission of different GHG livestock, paddy field and soils, as well as sequestering carbon in soil, along with increasing productivity and environmental conservations. As these are competing aims, priorities need to be defined and trade-offs considered.

v) Very good progress was achieved in measuring and reducing CH4 emissions from cattle, and reducing the GHG emission from fields by optimizing the water management. These activities focus on single crops and single fields. An important issue is considering the GHG of different crop rotation systems in relation to their productivity.

vi) The activities are very broad and not all sectors may equally contribute to the reduction of GHG emissions. Therefore, it will be important that the developed technologies and their potential of GHG reduction are periodically evaluated to make sure that research resources will be dedicated to those sectors with the greatest potential of GHG reduction.

vii) The main emissions of the Japanese food system are generated abroad. Therefore, a socio-economic research line might assist to analyze and recommend changes of consumer awareness and behavior, as this might be a further important parameter of GHG emission.

viii) A focus on technologies should not mask the role of socio-economic barriers (including costs) for agricultural mitigation. A mitigation abatement cost curve showing both the technical potential and the costs could help prioritize options with a relatively low cost. Another criterion concerns the technology readiness level (TRL), since technologies with a low TRL are unlikely to be ready for large scale adoption before 2030. High TRL and low-cost technologies are likely to have the most potential to enhance agricultural mitigation adoption by 2030. Nevertheless, exploring low TRL options is also needed for later (2050) time horizons.

ix) Beyond rumen manipulation technologies through probiotics, various feed additives (ranging from a patented chemical – 3-NOP- to plants rich in specific secondary compounds and lipids, and to red algae rich in bromoform) have already been shown to mitigate methane emissions from ruminants in commercial farms, but their development and adoption may benefit from further research.

x) For paddy rice, much progress has been achieved with a high technology readiness level and low-cost option concerning extended mid-season drainage, complementing the alternate wetting and drying system which has already been tested extensively for methane mitigation. These changes in farming practices have a low cost and are already supported by the J-Credit system developed by Japan in cooperation with other Asian countries. It would be useful to have a systematic monitoring of these options through earth observation.

xi) Arable soils emissions. One project concerns N_2O emissions by soybean and its mitigation by selecting Rhizobia strains able to fully denitrify through the $nosZ^+$ gene. The results presented are at low TRL (pot scale experiment), but a previous publication has shown reduced emissions at field scale despite competition with native soil Rhizobia strains. Further progress in inoculation methods would be needed to upscale this technology.

xii) The incentives for farmers to buy and apply biochar were not fully clear. The adoption rate of this technology could be low without subsidies since the costs of biochar is usually high.

xiii) Another question concerns the CO_2e balance of biochar production and use as estimated through lifecycle analyses (LCA). Since the project targets biomass wastes (e.g. rice husks, fruit tree pruning, etc.) this balance may be favorable. However, care should be taken not to impoverish in the long-term some soils by transferring carbon as biochar to other fields.

NARO Response to the Comments of the Reviewers

i) We are improving the sniffer method by enhancing equipment, measurement techniques, and calculation methods. Additionally, we are increasing the number of experimental farms to verify system accuracy.

ii) Your feedback highlights the importance of evaluating multiple GHGs and reducing emissions while optimizing productivity. We will continue our research, including studies on biochar.

iii) In our reviews, we presented research on model-based comprehensive evaluations and visualization, which includes various environmental impacts beyond GHGs. We will continue to develop this research and strive to conduct long-term studies as you suggested.

iv) Considering trade-offs is crucial. With this in mind, we aim to develop technologies that balance productivity and environmental conservation.

v) It is important to focus on various rotation systems, not just a single crop. For methane emissions from rice fields, we evaluate N_2O and soil carbon within the rotation cropping system and continue our efforts.

vi) We believe it is crucial to prioritize agricultural areas which emits significant amount of GHG and reduce them. For instance, we are focusing on rice field methane exploring ways to reduce all three major GHGs.

vii) We think it is an important point. Currently, GHG emissions from food production are calculated as emissions from producer countries. Discussions have started within and outside NARO on how to incorporate these emissions into the food system considering socioeconomic perspectives such as retroactive application of environmental values to consumers, consumer behavior and food trade. We believe it is crucial to show that reducing GHGs can be achieved through both production and consumption.

viii) We are developing cost-effective, low-labor technologies with high Technology Readiness Levels (TRL), such as extending the drainage period in paddy fields. These efforts are supported by government environmental payments and credit systems to promote early adoption. Additionally, we are working on innovative technologies like low-methane rice varieties, and microbiological methods to reduce N_2O emissions. It is important to balance both approaches to mitigate climate change. For example, amino acid-balanced feed, which reduces nitrogen excretion in livestock, is becoming popular due to its comparable cost to conventional feed. We are also researching technologies that significantly reduce GHG emissions but are relatively high in cost.

ix) We will continue to research methane emission control in cattle using probiotics, aiming for social implementation. Additionally, we will study the effects of chemical and natural substances with methane reduction properties, including their combined use, to promote social implementation.

x) Extending the drainage period has high TRL, is cost-effective, and is spreading due to J-credits. We recognize that systematic monitoring through global observations is useful in maximizing effectiveness, and we have begun some of these efforts.

xi) This technique still has a low TRL and needs better inoculation methods for field application. We are working toward this goal.

xii) Your point is important. While obtaining credits can be an incentive, it is not enough. We aim to offset costs by developing highly functional biochar with microbial functions to enhance productivity.

xiii) LCA is essential. We evaluate the life cycle of biochar, including production, transportation, and application. It is problematic if soil fertility decreases due to biased application of biochar or other organic matter like compost. Therefore, we must pay attention to this issue.

Program 4: Innovation in plant protection

The rating is: **S –** to maximize the results of R&D, the creation of particularly noteworthy results or the expectation of excellent results in the future are recognized**.**

Overall Comments from the Peer Reviewers

NARO’s research program, Plant Protection Innovation, aims to reduce the use of chemical pesticides by 50% by 2050 in accordance with the MIDORI strategy for sustainable food systems, MAFF. It promotes the innovation of environmentally friendly plant protection methods that adopt the principles of integrated pest management (IPM) and organic manufacturing. Specifically, in addition to pest control using conventional predators and parasites, this includes physical control methods such as highly innovative laser shooting and ultrasonic techniques, as well as the development of biological control agents and intracellular symbionts. They are also working to improve pest control strategies through AI and pheromone monitoring, and to establish a cross-border pest forecasting system. These initiatives contribute to Japan’s goal of reducing the use of chemical agricultural chemicals and are an important step toward the realization of sustainable agriculture. The following are recommended for future direction.

The following are recommended for future direction.

i) Develop realistic testing scenarios and protocols for integrated pest management systems that can test new technologies (e.g., laser shooting, ultrasound, and biocontrol agents) is recommended. Better understanding of actual field viability could lead to a holistic approach to pest control that minimizes environmental impact.

ii) Continue to enhance and adapt the pest forecasting systems for use in other relevant countries, by focusing on collaborative AI and computational simulations research to address transboundary pest challenges is recommended. Continuous model refinement and improving data collection are critical in improving food security across the region.

iii) In general, the research of the institute is predominantly basic, highly innovative and novel, which might bear the risk, that considerable chunks of the work might not be applicable in practice. My recommendation is to integrate also more applied research lines, picking up the most important pests and diseases and develop and optimize biological and physical control methods which might be quickly adopted by farmers.

iv) While these innovations are promising for renewing crop protection strategies and reducing the use of chemical pesticides, their adoption in commercial farms through IPM programs seemed to be very limited so far. More attention could be given to the integration of several technologies to reduce chemical pesticide use. This may require a network of agro-ecological farms to test innovations at farm scale and co-design with farmers their local deployment.

v) This program has provided a proof of concept for high-tech environmentally friendly technologies, including laser-based, ultrasound-based pest, sterile-male and parasitoid-based pest control methods. However, each of these technologies will need to be approved by regulatory agencies before being used in commercial farms. To this end, significant efforts need to be invested in risks assessment and in training of potential users to mitigate possible risks.

vi) Monitoring the deployment of both low and high- tech approaches would be useful to understand how each approach could be deployed further and how they could become integrated within IPM programs across cropping systems.

vii) The advanced monitoring of the migratory routes of fall armyworms and planthoppers and the development of pheromone traps and of AI counting tools are major achievements for cooperation in Asia on plant protection. This approach could be further developed through cooperation with other world regions such as Africa.

NARO Response to the Comments of the Reviewers

i) We are developing these technologies to lessen the environmental impact of chemical pesticides and reduce the workload for producers. For laser shooting, we plan to conduct verification tests at NARO and consortium test sites over the next five years, aiming to create affordable, compact devices. Ultrasound technology has been tested at over 20 production sites and is now ready for sale, with detailed usage instructions published in a standard operating procedure manual for immediate use by producers. For biological control agents, we need six successful field demonstration tests to register them as agricultural chemicals. We plan to gather and register this data at NARO and consortium test sites. We have already started consulting with several private companies and preparing for commercialization.

ii) We are tackling the issue of cross-border flying insect pests in collaboration with China, Thailand, Vietnam, Taiwan, and other countries. Specifically, we are promoting international joint research with China and Taiwan to develop advanced forecasting systems for pests like the fall armyworm, plant hopper, and citrus fruit fly, and we will continue to strengthen these relationships. Additionally, we are conducting joint research with Thailand and Vietnam on managing drug resistance in the fall armyworm and plant hopper, respectively. In 2024, we accepted technical trainees from Africa to train on the arrival prediction system for the fall armyworm, contributing to the development of pest management technologies in Africa. We will continue to improve our models and data collection.

iii) Concerns about laser sniping are significant because it involves new initiatives that have never been undertaken before. Therefore, we have selected *Spodoptera litura*, a major crop pest, as our target. We believe this will expand the scope of social implementation and lead to the provision of affordable devices. Regarding ultrasound, we think it will pave the way for practical application and social implementation by conducting pest control tests targeting major insect pests like *Spodoptera litura* and tobacco budworm. As for natural enemies, similar types are already available on the market, so the hurdle for practical use is low. We believe it is realistic because we have the prospect of introducing products with higher performance than existing ones, and we can expect the development of crops (such as strawberries) that have not been used before. The commercialization of symbiotic microorganisms is still in the future since these are new initiatives. However, basic research has been enhanced, and we aim to achieve steady results by targeting important pests with broad feeding habits.

iv) With the help of local public research institutions, we have been working on a program called IPM which combines natural enemy utilization technologies and local cultivation system. This program will reduce agricultural chemicals. With this program we have collected feedback from local producers and have been working on demonstration and dissemination. We have also been working on demonstrating and disseminating these technologies, incorporating ideas from local producers. It took a long time to deploy these pesticide-reducing technologies in the local community. The introduction of innovative technologies will occur in the future. However, as you pointed out, for rapid dissemination, we need to use a network of agroecology-oriented farms. We aim to develop an IPM program that integrates innovative technologies (e.g., natural enemies and lasers) in collaboration with field engineers and scientists, demonstrate these technologies on multiple farms, and promote their adoption in the local community.

v) To prevent accidental firing of lasers at people, we are working to implement safety measures such as automatically stopping the laser when a person is detected by the camera. Additionally, we will establish a system that ensures safe use of this technology by disclosing standard work procedures and providing technical guidance. To register biological control agents as agricultural chemicals, we will present data that can be evaluated for ecological risks and obtain approval from the Ministry of Agriculture, Forestry and Fisheries. Therefore, we plan to gather such data. For symbiotic microorganisms, pest control using sterile males and symbiotic microorganisms has been implemented in mosquitoes that transmit dengue fever overseas. By combining laboratory experiments with mathematical models, we will evaluate the effects and risks in a neutral manner and work on technological improvements to enhance effectiveness and reduce risks. We also believe it is necessary to focus on public awareness activities to prevent misunderstandings among the general public.

vi) Laser technology alone cannot cover all pests, and the selected natural enemy technology alone cannot cover all of them. For this reason, we will develop technologies based on the assumption that they are integrated with existing chemical pesticides and technologies (such as Indigenous natural enemies) and aim to construct an optimal IPM control system by smoothly adding or replacing existing technologies.

vii) We are addressing the issue of transboundary flying insect pests in cooperation with China, Thailand, Vietnam, Taiwan, and other countries. Specifically, we are promoting international joint research with China, Taiwan, and others on developing advanced forecasting systems for pests like the fall armyworm, plant hopper, and citrus fruit fly, and we will continue to build these relationships. We will also conduct joint research with Thailand on a new pheromone trap developed for the fall armyworm, making improvements so it can be used to predict occurrences and disrupt communication in Thailand. Additionally, we are conducting joint research with Thailand and Vietnam on managing drug resistance in fall armyworms and plant hoppers, respectively. In 2024, we accepted technical trainees from Africa to train on the arrival prediction system for the fall armyworm, contributing to the development of pest management technologies in Africa. We will continue to work to improve food security across the entire region. To develop a counting tool using AI, we are promoting its use in the domestic market. However, we believe that exchanging information with other countries, such as those in Asia, is necessary.

II. Research Vision of NARO

Overall Comments from the Peer Reviewers

NARO is at the forefront of Japanese agricultural research, adopting innovative approaches to tackle various agricultural issues by utilizing advanced techniques such as AI. As a national research and development agency, it is responsible for a wide range of fields. Its activities are deeply integrated into Japanese strategies, such as the MIDORI strategy for sustainable food systems, and Society 5.0, with the aims of ensuring food security and self-sufficiency, strengthening global competitiveness, expanding exports, and contributing to environmental conservation. It is also working with international partners to promote interdisciplinary research aimed at improving sustainability, productivity, and resilience, and addressing complex scientific issues.

The following are recommended for future direction.

1) Recommendation for overall research vision of NARO

i) NARO should continue to invest in AI and computational efforts. Grow capability and leverage big data and AI technologies to improve agricultural decision-making processes. Developing comprehensive data platforms that integrate meteorological, soil, and pest data can provide farmers with actionable insights, enabling them to optimize resource use and improve yields while minimizing environmental impacts.

ii) As climate change poses significant risks to agriculture, NARO should continue to invest in research that enhances the resilience of crops and farming systems. This includes developing climate-smart agricultural practices, exploring drought-resistant crop varieties, and implementing adaptive management strategies that can mitigate the impacts of extreme weather events.

iii) Collaborative research initiatives can enhance the development of advanced technologies, such as AI-driven pest forecasting systems and precision agriculture tools, ensuring that NARO remains at the forefront of agricultural research. Building robust partnerships with universities, private sector companies, and international research organizations will facilitate knowledge exchange and innovation.

iv) To ensure that research findings are effectively translated into practice, NARO should continue its outreach and education efforts. This includes creating accessible training programs for farmers and agricultural stakeholders on sustainable practices, pest management technologies, and the use of new tools and methodologies.

v) The flow of science-based information into political decisions and into public awareness and into practical applications by the famers should be considered as different but equally important directions of knowledge transfer.

vi) The broad spectrum of expertise and research fields allows NARO to pursue excellent interdisciplinary research and to address complex scientific questions. To further develop the human resources, strong cooperative connections with national and international research institutes are necessary and should be further strengthened.

NARO Response to the Comments of the Reviewers

i) Thank you for understanding our research and development strategy. Since President Kyuma's appointment in 2018, we have strategically enhanced technological developments using AI and big data. This has led to concrete results, as introduced in the review. We will continue to invest in this area and collaborate with RCAIT and other research institutes to produce practical research outcomes.

ii) We are promoting agricultural technology development that adapts to climate change as part of our mission to balance productivity improvement and environmental preservation which is one of our three missions. In the future, we will continue to strengthen the development of crop varieties and research into agricultural systems to enhance environmental resilience.

iii) As you pointed out, we have strengthened collaboration with other organizations to develop advanced technologies through joint research. This includes the 'Remote Farming Support System' project with major domestic telecommunications companies and the Moonshot R&D program with universities. Globally, we plan to conduct fermentative research with INRAE and integrate AI and agriculture with LLNL. We aim to create innovation by further strengthening these collaborations.

iv) NARO does not have an organization for directly educating and disseminating research findings to farmers. Instead, we collaborate with prefectures that have local agricultural experimental stations and extension centers. Since 2019, NARO has developed Standard Operating Procedures (SOPs) for major R&D results to help disseminate research findings; as of 2025, 145 SOPs have been prepared.

v) As you suggested, it is important and is our mission for us not only to implement our research results in the agricultural and food industries but also to use the scientific knowledge obtained for political decisions and to contribute to the improvement of scientific literacy in society.

vi) Among interdisciplinary studies, we believe that integrating AI and ICT with traditional agricultural and food research should be more vigorously promoted to address diverse and complex issues. We recognize the importance of collaboration with various domestic and overseas research institutes and will continue to make positive efforts.

2) Recommendation for research direction of 'smart breeding'

i) The presentation did not include a reference to gene editing and focused on smart breeding and the potential of AI for breeding. It may be useful to expand the NARO vision on smart breeding to the role (and potential risks) of gene-editing as this method is gaining momentum worldwide.

ii) Breeding should now contribute not only to productivity, but also to the tolerance to both abiotic and biotic stresses and to the greening of agriculture through the limitation of inputs such as fertilizers, chemical pesticides and irrigation water. These challenges are interlinked since a low-input agriculture may be less productive, and since plant traits conferring resilience to heat, drought and flooding may also lead to lower yields under optimal climatic conditions. Integrative responses need to be found by smart breeding in combination with best agronomic practices.

iii) Not only should smart breeding consider the adaptation of the current main crop species, but also the possible need to breed alternative crop species for their future use in a warmer climate (e.g. sorghum in replacement of maize if irrigation water availability becomes limited). This will require the exploration of genetic resources in Japan and possibly in other countries to find the suitable traits, thereby progressing towards climate smart breeding in order to ensure the resilience of crop production to future climate conditions.

iv) Smart breeding should balance two dimensions: genotyping and phenotyping. Over the two past decades, genotyping methods have enormously progressed, while less emphasis has been placed on phenotyping. This results in the current situation where the main roadblock concerns high precision phenotyping under realistic ‘field like’ conditions of plant growth. Moreover, despite extensive research the understanding of the genetic regulation of a number of complex plant traits (e.g. yield) is still relatively weak. To make progress functional crop models informed by phenomics can be used to better define the genetic targets for breeding.

v) Beyond the use of controlled environment platforms, allowing to select genotypes while avoiding potential confusion with environmental interactions, it will be needed to expand the phenotyping capacities and to critically phenotype plants under abiotic stresses expected to rapidly increase under climate change (e.g. high temperatures, elevated CO_2, etc.). This can lead to a more rapid selection of genotypes having traits conferring resilience to climate change.

NARO Response to the Comments of the Reviewers

i) Gene editing is researched, and techniques are developed due to its effectiveness in designing crops for targeted performance and in developing crops with greater diversity compared to single gene mutation.

ii) We aim to efficiently select the optimal genotype under required environmental conditions by developing a trait prediction model that incorporates environmental effects and by collecting and accumulating phenotypic data under conditions such as high temperature and low fertilizer.

iii) By developing a trait prediction model that incorporates environmental effects in major crops, we want to efficiently select crop species and optimal genotypes according to environmental conditions.

iv) Institute of Crop Science (NICS) has established a facility that mimics a field-like environment in growth chambers and implemented a non-destructive plant measuring system. We monitor plant development and genetic expression. Using omics data, we are attempting to construct a crop model suitable for a specific environment. Based on this model, we will be able to select candidate gene targets for breeding in the future.

v) NICS has installed a facility that mimics field-like conditions in growth chambers and allows year-round plant cultivation and measurement under conditions of high-temperature stress, drought stress, and high CO_2 concentrations.

3) Recommendation for research direction of 'food loss and waste'

i) It should be noted that current short-term tensions on e.g. high-quality rice availability in Japan and future uncertainties caused by climate change may result in the need for strategic grain stocks. If so, post-harvest losses could increase since it is not easy to conserve grains and other food commodities on a large scale. This perspective may need to be integrated in NARO's vision on food loss and waste, as it would require studying technologies for long-term grain conservation.

ii) The dominant part of the food waste happens at the stage of retail, and of domestic consumption and food catering. Over-consumption of food at this stage is harmful for consumers (e.g. for nutrition and health) and for the environment and contributes to the abnormally high true cost of food. Nevertheless, food wastage increases the sales of the agri-food sector. Such an issue could be addressed by regulatory measures, price signals and changes in retail, catering and consumers behaviors. However, to my understanding, NARO does not develop research in socio-economics. Therefore, its contribution needs to be focused on changes in technologies that could help reduce food wastage.

iii) So far, food waste is the dominant component of the loss and waste issue. There are clear economic incentives to minimize food wastage in agri-food transformation industries and these industries tend to optimize the valorization of co-products and by-products (e.g. for animal feed, for biogas production, etc.). Nevertheless, innovative valorization of by-products may be of interest (e.g. for insect proteins, a production more likely to be used as feed than as food). Innovative ways of valorizing co- and by-products of agri-food transformation chains are therefore of clear interest for NARO's vision on food loss and waste.

iv) Extending the shelf life of food is likely to help abating food wastage. Research on new fermented food and other ways to store food products, while avoiding extra reliance on the cold chain is highly relevant for technological innovation to reduce food wastes. Conversely, innovation in the cold chain and its logistics can also be relevant, especially since adaptation of the cold chain is required in the face of heat waves that may reduce its efficiency.

NARO Response to the Comments of the Reviewers

i) Although research on grain storage and preservation technology has been decreasing, we continue to develop technology to control stored grain pests and promote the practical application of pest control technology that does not use chemicals and has a low environmental impact. Due to global warming, the risk of mold generation and mold poisoning in grains may increase. Therefore, we are developing detection, generation prediction, and prevention technologies for harmful mold and mold poisoning. We will work closely with food security research and development to proceed with this research appropriately.

ii) The ratio of food loss at the downstream stage, such as household consumption, is as high as 47%. We recognize the importance of reducing food loss at the consumption stage in combination with retail and restaurant operations. Therefore, we believe it is necessary to develop technologies that lead to changes in consumer behavior, such as extending expiration dates, optimizing safety factors, reducing unsold inventory, and minimizing expired and leftover food. NARO will promote the dissemination and practical use of innovative refrigeration and storage technologies and develop methods to accurately evaluate the nutritional value, safety, and other qualities of foods. At the same time, we will accelerate R&D to reduce food waste by proposing recipes that utilize residual foodstuffs in the home.

iii) NARO is actively working on upcycling by-products and researching ways to reduce food waste. We are using Japan's specialized fermentation technology to develop recycling technologies for non-food products and upcycling food into new food products. For example, we are producing substitute meat using Aspergillus oryzae and whey, and producing valuables like lactic acid using rice straw. We have also established a NARO Lactic Acid Bacteria Database, which compiles data on about 6000 Lactic Acid Bacteria strains owned by NARO, and have begun to disclose it as a web service.

iv) From the perspective of energy consumption and cost reduction, we recognize the importance of not relying excessively on refrigeration chains. Therefore, we are developing new sterilization technologies that allow long-term storage of foods at room temperature using electrical and high-pressure treatments. These technologies help produce foods that retain their flavor, nutrients, and other qualities better than conventional methods. We are also working on creating an efficient refrigerated chain by collaborating with a private company to develop a system that maintains the freshness of fruits and vegetables during transportation using a highly insulated sealed box. Additionally, we have started to work on partnering with start-ups and other companies to develop technologies for preserving freshness and sensing quality in fresh food, thereby contributing to innovations in food distribution.