

Development of environmentally friendly approaches in plant protection for sustainable agriculture: Status and prospects

Review Report

The reviewers provided the report on the NARO Research Program “Development of environmentally friendly approaches in plant protection for sustainable agriculture: Status and prospects”. NARO scientists responded the report as follows:

General comments

The research program of NARO is making important investments in innovations for management of pests and pathogens in increasingly sustainable ways. The quality of the work is very high and NARO’s scientists are at the cutting edge of their fields. The current investment in NARO research will be very important to Japan, where pesticide use has been very high. The agroecosystems (at least that we were shown) are ideal for deployment of innovative strategies for control. The field sizes are relatively small and the plantings are more diverse than is common in the United States and much of Europe. It is particularly impressive that research investments are resulting in decision tools for protection officers, control strategies that transform the waste stream into useful technology, biocontrol with natural enemies and inducers of plant defense, pheromones and management of pesticide resistance in pests. All of the projects we reviewed represent important investments in Japanese agriculture that NARO must continue. Clearly, increased self-sufficiency in production of food will benefit the people of Japan. The approaches, directions and applications that we observed are excellent.

Nevertheless, farmers are deserting their lands, choosing not to farm, or to keep the land fallow for an extended period of time. Furthermore, policy decisions appear to have reduced innovation in this field in Japan; while other countries continue to make strides in using advanced genetics to identify solutions that provide the promise of reducing the use of agriculture chemical in the future. As a consequence, a) the administrative leaders of NARO are urged to take a more active role in planning the future of crop protection that has a strong complementary component of plant breeding and plant biotechnology to complement the ongoing work. By combining the efforts of plant breeding with crop protection, it is likely that the total work force, and therefore cost, of developing useful strategies can be further controlled, while meeting the goals for agriculture.

It was noteworthy that there was no mention of using microbial solutions to meet the goals of pest and pathogen control. There is a renewed interest in academic labs as well as in private sector labs, to develop biological controls, including using biological products per se, as well as using live microbes to control fungi, bacteria, nematodes and insects. This is an area of research and product development that is built upon advanced and genomic sciences, studies of biodiversity and biocontrol, and extensive field research: b) NARO should consider building this capacity, perhaps by redirecting existing staff effort and funding.

Due to the small fields, a highly diverse land structure and a great variety of crops there is a large potential for conservation biocontrol protecting and promoting naturally occurring antagonists. c) Such a research line might complement the existing program on “Development of environmentally friendly approaches in plant protection and sustainable agriculture”.

Our climate is changing, the data is convincing. Sea levels are rising and the agricultural enterprise must produce food for more people with less arable land and available water. Pest distributions will continue to shift with the climate. d) It makes a lot of sense for NARO to invest in research that focuses on pest management in light of these climate changes. As the population and demographics of agricultural practitioners is rapidly changing in Japan, this area of inquiry becomes even more important. Perhaps Japan has an opportunity to become more self-sufficient as the country actually is seeing an increase in availability of arable land. e) This goal will require investment in

agricultural scientists; but also in social scientists to address the “people” oriented aspects of these issues.

In addition to the complement of scientific areas above mentioned, recommendations to improve the program are listed in the following:

1. f) Increased investment in extension of new strategies to producers and making tools directly accessible in every way possible, whether through private companies or other institutions in Japan. In many cases, steps to commercialization of products that are outcomes of the research done have already been taken by the research groups we reviewed. g) The more streamlined this can become, the greater impact NARO will have. In some cases, it may be that investment in social scientists that can help plan and implement public acceptance of new technologies may be of value.
2. h) NARO should develop program to improve international cooperation with research partners from other countries facing similar challenges and following similar aims of reducing the impact of chemical pesticides. International collaboration would help to increase the quality, use of resources as well as the visibility of the research performed.
3. i) Common education programs as well as close cooperation of NARO scientists and universities will provide better chance to attract young talents at an early stage of their education and making NARO an attractive place to perform basic and applied research for agriculture. To achieve this goal, it is recommended to develop incentives to improve integration of Master and PhD students into the research projects carried out at NARO and to tighten the cooperation with universities and other research institutions in Japan.
4. Cooperation among scientists within NARO appears well established and groups of researchers cooperating on different topics are installed and work fruitfully together. j) Research topics and grade of internal cooperation should be regularly internally reviewed for potential of improvement.
5. k) Continued publication in internationally accessible journals is highly recommended.
6. l) Invest in gender diversity in the scientific enterprise. Increased diversity of thought, approach and leadership, brings positive developments to institutions worldwide and will benefit the research enterprise of NARO. Increasing the number of women in STEM fields has been a benefit in many parts of the world. Abundant data supports the value of this goal and research enterprises worldwide are working hard to change the demographics of STEM research, which continue to be largely male dominated. Increased gender diversity will allow NARO to continue to be at the forefront of science on an international level.

NARO responses to the comments of the Evaluation Committee (Alphabets show correspondence between comments and responses)

- a) According to the statistics compiled by the Japanese Ministry of Agriculture, Forestry and Fisheries, 22% of inquiries from farmers and others involved in farming are related to crop protection, making it the most common matter of inquiry. It appears that the awareness of pest risks is particularly high among producers. Therefore, the findings of researches in the area of crop protection should be applied to not only the development of pest control techniques, but also the development of new crops that take advantage of plant biotechnology. In this milieu, we at the NARO believe that the applied research area focusing on crop protection and basic research area focusing on plant biotechnology should share issues, and together should establish and steadily execute a specific crop breeding research strategy for efficient pest control. Through this, individual research areas should be able to set their goals more clearly and manage their research projects more specifically.
- b) In Japan, the use of microorganisms in agriculture is limited due to the legal regulations. At the same time, however, advancements in microorganism-based agricultural techniques that lead to improvements in production are considered to benefit the industry. The search for beneficial microorganisms is a long-term process and requires the development of efficient selection methods; however, the funds from private sectors and time are limited. Furthermore, such mid- and long-term selection programs are not suitable to

universities where researchers have to constantly publish research papers. Considering these, we believe that NARO, which can effectively use public funds in its independent plans, will contribute to future development of this area of research.

- c) In Japan, agriculture is practiced in hilly and mountainous areas on a small scale, and employs a multi-crop production system. Therefore, we believe that integrated pest management (IPM) is suitable for agriculture in Japan. In this milieu, promotion of development of IPM techniques that effectively use biocontrol agents, such as natural enemies and antagonistic microorganisms, is a pressing issue. We strive to make the IPM-based crop production system a standard practice in Japan by continuing to actively engage in activities that lead this area of research.
- d) Situated in Northwest Asia, Japan is highly influenced by the prevailing westerlies from China. As discussed in the lecture on the review by overseas researchers, in Western Japan, pests emigrate from China on the westerlies and carry pathogens. Furthermore, climate change on a global scale, which has recently started showing non-negligible effects, might change the course of the prevailing westerlies. In pest research, we will accurately forecast and appropriately assess the effects of climate change on pests and domestic agriculture by collaborating with other areas of research conducted within the NARO, including those on climate and environmental effects, and by exchanging information with overseas research organizations.
- e) Recently, at NARO, in addition to the development of productivity-enhancing techniques, research has increasingly focused on analyzing the effects on rural communities of introducing such techniques to agricultural practice. We are comprehensively assessing the effects of new techniques in a production system by collaborating with social science researchers specializing in agricultural management, examining aspects such as infrastructure required by new farmers to continue their businesses and the establishment of an operating system to effectively maintain and expand farming businesses. We believe that we should continue to maintain and develop this approach.
- f) At the NARO, we have been introducing the techniques developed and knowledge obtained to various external organizations through broad-based extension activities so that these findings can be used by farmers and private companies that make products based on such research findings. To strengthen this extension function, some research institutes within the NARO have recently been employing industry-academia collaboration coordinators and agricultural technology communicators, thereby improving our communication with external entities.
- g) It often takes some time for new techniques to be introduced to and become widespread among producers. This is particularly the case with genetically modified biological agents. In Japan, there is a vague sense of fear toward genetically modified crops among not only consumers, but also producers. Currently, such crops are not accepted in the country. To ensure that the biological agents developed using emerging genome editing technologies, and such scientific findings and their applied technologies are smoothly accepted by the society, we believe that a social science approach is essential.
- h) At the NARO, the International Office was established at the headquarters under the fourth mid-term plan to expand the system in order to strengthen international collaboration among research institutes. The NARO concluded a collaboration arrangement with Wageningen University, Netherlands, and since then has engaged in research information exchange and technical cooperation with them. Based on this review of our research by overseas researchers, the NARO is currently exploring the possibility of collaborative research on biological control technologies with Julius Kühn-Institut, Germany. The NARO concluded a memorandum of understanding (MOU) with the All-Russian Institute of Plant Protection established under the Russian Academy of Sciences. Furthermore, it is about to commence a collaborative research with them on epidemiological surveys on plant diseases and other related areas. Furthermore, the NARO carries out projects to strengthen international collaboration to facilitate collaboration with overseas researchers at the individual level. Our researchers seldom actively collaborate with overseas researchers; however,

through various domestic and international modes, we will support our researchers to achieve it.

- i) The NARO actively promotes research information exchange and technical cooperation through collaboration arrangement with neighboring universities and universities that specialize in fields similar to that of the NARO. However, as the NARO is not permitted to conduct education-related operations, we do not exchange information with graduate and undergraduate students, except under special circumstances. However, as the NARO has a role to play as an education institution, if credit recognition becomes possible through exchange of programs with universities and other institutions with which the NARO has a collaborative agreement, we will be able to accept graduate and undergraduate students.
- j) At the NARO, pest-related researchers are divided into groups that exchange information with each other. They hold discussion meetings once or twice a year to share their progress in research. With an aim to develop technologies that produce effects at the point of production, we will promote the development of technologies required by producers through collaboration with staff at experimental stations established by local governments and private companies, as well as through internal collaboration.
- k) We believe that it is essential for researchers to report their research findings as academic papers. However, English proficiency varies greatly among Japanese researchers. Therefore, we have set aside a budget for English translation to enable our researchers to publish papers in international journals. We will encourage our researchers to actively publish papers in international journals using this budget.
- l) At the NARO, we have targeted 30% as the proportion of women among new recruits and 10% as the proportion of women managers by 2020.

Section 1 Present state of pest and disease management for Japanese crops

Project 1 Management of migratory insect pests in monsoon Asia and the quarantining of pests

Detection and monitoring tools are developed and applied for important disease agents and migratory pests, such as Rice plant hopper, Southern rice black virus, Oriental fruit moth, Citrus greening disease. Plum pox virus detection and sampling of its vector *Aphis spiraecola* is nation-wide used. Monitoring data are transformed into models for migration and prediction of occurrence of migratory pests and of diseases.

Use of these kinds of data to provide risk-based decision tools for pest management practitioners and producers will be critical to wise and sustainable strategies for pest control. The researchers are working on creating tools that will allow producers in Japan to be proactive in detecting and managing a wide range of pests and pathogens. In several cases, the researchers have overcome major hurdles, i.e. in developing a system for cultivating and detecting *Candidatus Liberibacter asiaticus* (Clas).

a) Models of Rice plant hoppers, however, are not well connected to population size in origin countries, wind and weather conditions. Predictions might be too late to react. It would also suggest that the tools developed should be carried a step further and made accessible to growers in real time on a web platform so that they might take pro-active actions, such as altering their planting dates or other management strategies.

b) In addition, the report would benefit by indicating how each results of each project will be used to restrict disease, or reduce use of chemical pesticides. In the case of Citrus greening disease, although the advances in detecting it appears to be novel, perhaps a break-through, it is unclear how this will be used to develop treat the disease, other than by eradication

c) Extension of methodology to further agricultural important pests and diseases would be expected. Consideration should be given to cooperation with other countries. The rating is: **A – good quality and minor revision needed.**

NARO responses to the comments of the Evaluation Committee

- a) Rice planthoppers that are found in Japan are believed to have migrated from China. However, as China's Ministry of Agriculture does not disclose pest occurrence information claiming that they are state secrets, we have not been able to incorporate the migration density of the pest at the source in our forecasting model. As our rice planthoppers migration forecasting model calculates their movement using wind velocities and temperature, this comment does not apply. The control targets the larval stage of the generation after the original generation that migrated to Japan. Furthermore, the pest control agencies of prefectural governments forecast the timing of control based on (1) forecast information, (2) density and age compositions at fields, (3) monitoring data collected using forecasting light and net traps, and (4) migration information, and announce forecast information. Therefore, the concern raised in the comment does not apply. Farmers can directly access our forecasting model and can determine the timing of control by conducting a survey using an insect observation plate. However, farmers commonly make decisions based on the forecasts issued by the pest control agency. In rice producing areas, the main aim of producers is to produce high palatability rice, and they commonly control planthoppers chemically. Due to reasons related to water availability and aftercrops, farmers rarely change sowing dates (planting dates) significantly to avoid planthopper damages.
- b) The development of a technique to artificially culture *Candidatus Liberibacter asiaticus*, a bacterium that causes citrus greening disease, now enables the definite diagnosis of the disease, contributing to the acceleration of the citrus greening disease eradication project in Japan. We hope to apply this technique to artificially culture *Candidatus Liberibacter solanacearum*, a bacterium, which during recent years has caused significant damage to Solanaceae and Umbelliferae species in Europe and New Zealand. Currently, in a joint research project with France, we are developing a high-sensitivity detection technology for *Candidatus Liberibacter solanacearum*. In the future, it will be used for plant quarantines as an international testing technology.
- In Japan, the number of chemicals permitted for use against kiwifruit bacterial cancer is limited. Therefore, it is necessary to give priority to preventive measures (i.e., measures to prevent the spread of the disease to areas where the disease has not been confirmed). Although such measures will not reduce the use of chemical pesticides as the type of chemicals permitted for use is small, they will allow precise preventive measures based on accurate diagnosis.
- In plum pox virus (PPV)-affected areas, seasonal variation in the emergence and virus carrying rate in aphids has been determined. Based on these findings, the optimum time to control aphids, a carrier, has been determined. This has contributed to the establishment of an effective aphid control system. It is believed that these developments are preventing the spread of PPV and reducing the unnecessary use of pesticides.
- c) As for migration forecast, we are investigating the possibility of including lepidopteran pests. As for planthoppers and oriental fruit flies, we have undertaken joint research with countries, such as Vietnam, China, and Taiwan.

Project 2 Development of an assay system for plant pathogens and insect pests with resistance or tolerance to agrochemicals and associated management strategies

Increasing resistance of pests and pathogens to chemicals pose a double threat: in case of resistance agrochemicals are mis-used or over-used and targets are not sufficiently controlled. Therefore, development of resistance monitoring tools and resistance management strategies are of premier importance to secure efficient pest and disease control. In different projects, molecular markers are developed.

This project was a good demonstration of how applied research can identify pests and disease, establish mechanisms of resistance to chemicals or other control mechanisms, and use the knowledge to develop alternative strategies, etc. Equally important is that the results of the research, including recommendations,

are disseminated to farmers so they can adapt recommendation to their farm situation.

a) The report will be more complete if the team leader would project forward 3-5 years and set expectations of how the knowledge will lead to further reduction in use of agrichemicals and over what time frame. Such predictions can help farmers to know what is coming in the future, and may be used to project future costs of farming/food production, as well as positive impacts on sustainability measure.

b) For further improvement, consideration should be given to increment of international collaboration because some resistance mechanisms might not be unique to Japan. In addition, tools and models developed for a number of pest and diseases can be extended to new targets and huge agricultural and environmental impact when implemented. The rating is: **S – high quality and no revision needed.**

NARO responses to the comments of the Evaluation Committee

a) In the next fiscal year (FY2018), we plan to prepare and make public the manual for managing pesticide resistance based on genetic diagnosis of cabbage moth, smaller tea tortrix, onion thrip, and cotton aphid. This manual will be distributed to prefectural experimental stations and pest control agencies, Japan Agricultural Cooperatives (JA) farm management support centers, and other entities through appropriate government departments. Subsequently, using the manual, the extension officers at these organizations can assess drug resistance risks in local agricultural production and instruct producers on appropriate drugs, their application methods, alternative control methods, etc. Consequently, unnecessary and ineffective use of chemicals against aforementioned pests is expected to reduce. Furthermore, by the end of this mid-term plan (FY2020), a reduction in the amount of chemicals used will be achieved.

b) Many important pests and the pesticides used to control them are universal, and therefore their drug resistance mechanisms are also universal. The Rothamsted Research, UK and other overseas research institutes are leading in the area of resistance mechanisms. As you pointed out, through international joint efforts, we expect that our research will advance, and that the outcomes obtained will have both domestic and international effects.

Section 2 Environment and conservation control measures for disease and pests in agricultural regions in Japan

Project 3 Breeding of natural enemies of insect pests and effective methods of using indigenous natural enemies

Projects aim at improving the use of beneficial arthropods for control of pest insects (aphids, thrips and white flies) and spider mites in green house. Many of these pests have developed resistance to chemicals. Important pests are addressed.

This project shows good innovation in developing methods for biological methods of disease control, with focus on predatory insects to control pests. a) Given, the high amount of pesticide applied in Japanese agriculture, strategies for deploying natural enemies are needed for this strategy to be well integrated. The project included developing flightless ladybugs to improve control aphid pests: while this and other bio-control strategies have limitations, work of this type should be continued with special care for public acceptance. Similarly, the creative ways for use of ‘banker plants’ shows that methods such as these can reduce the use of chemical pesticides. b) Such work is not easy but can be useful for Japan and other countries where demand for low pesticide use fruits and vegetables have a customer base that is willing to pay the increased costs of production.

c) The restricted use of only indigenous species may limit the applicability of beneficials. Cooperation and knowledge transfer with internationally active companies could be improved to identify the most important

applications and the best antagonistic organisms. In addition, any effort to streamline the licensing of indigenous natural enemies would help push their use forward more quickly. Certainly, the current research should help support such an effort.

Consideration should be given to the interference with biological control system by sprays of insects that cannot be controlled by beneficials. Large number of growers and small sizes of green houses may complicate implementations. The rating is: **A – good quality and minor revision needed.**

NARO responses to the comments of the Evaluation Committee

- a) Reduction in the use of pesticides is important as their copious use results in the development of pesticide resistance in pests. The need for reduction is also recognized in terms of reducing the burden on producers. Therefore, we are developing natural enemies as new control tools, and also methods to use them. In cooperation with field researchers at the prefecture level and using a variety of external funds, we are currently developing new control systems where chemical pesticides used in the existing systems are replaced with newly developed biological control agents. The control manual discussed in this presentation describes control system for different crops. We intend to carry out further research in this direction.
- b) In Japan, the market scale of low- or no-chemical agricultural products grown using natural enemies is relatively small. Contrarily, once the market scale expands, such products will lose their uniqueness and will be subject to price competition with other conventional products. Therefore, our aim is to (1) reduce the amount of chemical pesticides used by introducing natural enemies and (2) develop systems at cost and quality equivalent or superior to those of existing systems. We will also be seeking policy support as there are issues that are difficult to be solved with only technology.
- c) There seems to be a slight misunderstanding here. In Japan, the best-selling natural enemies include predatory mites *Phytoseiulus persimilis* and *Amblyseius swirskii*, and parasitic wasp *Aphidius colemani*; they are mostly introduced from overseas. These species are beneficial, and will be used actively in the country. Recently, in Europe, the use of native natural enemies has been attempted through breeding and other means owing to risks to biodiversity caused by the use of introduced natural enemies and the restriction of the export of genetic resources imposed by the Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (ABS). We expect that in the future the use of native species will increase in Japan due to similar reasons. With regard to the acquisition of patents for native natural enemies, their practical application might be accelerated through joint effort with the private sector to develop breeding methods and alternate feeds for natural enemy strains, and acquire patents. However, when the private sectors withdraw from such joint efforts, already acquired patents might impede the involvement of other businesses for realizing the practical application of new breeding methods and feeds.

Project 4 Development of environmentally friendly sterilization techniques against soil-borne diseases and nematodes and an assessment of its effectiveness

This project has developed new methods, and adapted results of other researchers to find ways to reduce soil borne diseases. For example, use of anaerobic soil disinfestation (ASD), and hot water treatment have previously been reported to be effective agents for sterilizing soils: the project team have adapted the procedure for Japan farmers with high success. The use of furnace char may be relatively more novel and is an interesting approach to increasing soil pH. Each method seems to be less costly and more efficient than use of chemical pesticides.

a) Did the team consider the cost of labor when comparing the cost of the new methods vs the cost of labor for chemical treatments? What is the uptake by farmers of these methods, what are cost savings? Currently,

the potential effects of the applied methods on soil microbiome are not well understood, and these methods may adversely impact soil biology. Therefore, a further research line monitoring these effects and developing methods to analyze soil microbial communities is highly recommended. Microbial indicator organisms may be established to judge soil quality. At the same time more deeply understanding the components of soil health, ecology and sustainability of cropping systems should be considered.

Health Checkup-Based Soil borne Disease Management (HeSoDiM) practices should be very helpful for producers to decide whether they need to fumigate or not. b) Can this guideline help mandate more responsible use of fumigation for Japanese producers? On the other hand, IPM principles, such as crop rotation, should be implemented without diagnosis as a regular management tool.

c) For future direction, research on microbial control to improve soil fertility is suggested. The rating is: **A – good quality and minor revision needed.**

NARO responses to the comments of the Evaluation Committee

- a) In Japan, farm land units are small and the cropping system varies with region. Therefore, it is important to select soil disinfection methods that suit individual circumstances. Regarding some disinfection methods discussed, management consultants have been hired to analyze whether material costs, labor required to adopt such technologies, and post-adoption yields are satisfactory for farm management. In addition, we have been investigating changes in soil microbiota following soil disinfection by establishing several experimental systems. It has been shown that the effects of hot water soil disinfection are enhanced by soil microorganisms. Furthermore, microorganisms that are indicative of resistance to soil diseases are being discovered. The changes in soil metals and nutrients following disinfection will be investigated in the future. It is necessary to tackle these problems in association with soil fertilizer research.
- b) We expect that the Health checkup based on Soil-borne Disease Management (HeSoDiM) will prove to be an important support tool for stable farm management. The range of strategies for farm management will significantly expand if this system can provide farmers with options in relation to not only soil diseases, but also soil fertilizers and next crops in rotation cropping. We will continue to promote further developments of this system.
- c) The effective use of soil microorganisms is important to improve soil fertility and suppress soil diseases. Analysis of soil microbiota following soil disinfection is under way, gradually revealing predominant types of microorganisms. It is expected that such microorganisms can serve as indicators of stably productive soil. Further research will aim to develop stably productive soil based on such indicator microorganisms.

Section 3 Near-term technologies for plant protection using biological functions and/or the properties of plants and insects

Project 5 New technologies for physical pest control using colored light or sound waves

The projects aim to control pest insects by exposing the pest insects or beneficial to physical stimuli impacting their behavior in a positive or negative way. Targets are smaller tea tortrix, the host-beneficial system Thrips-*Orius sauteri* and *Spodoptera litura*. The work in this project is both novel and scientifically interesting, and based on interesting hypotheses. The use of wavelength specific light and sound to control certain pests is innovative. And like other methods, may fit into production of fruits and vegetable in Japan where consumers may be willing to accept increased costs of produce with low residues.

a) Adapting the technology to a greenhouse situation, with the potential for applications to field situations is interesting and should be pursued to the next steps toward proving the technology and taking it to commercialization with patenting, if possible. Non-target effects should be addressed. In general, physical

methods are not highly specific and therefore may interfere with a broad range of non-target organisms. This challenge is in part mitigated by using optimized ultrasound wavelength patterns. b) Evaluation of the long-term effects on the insect populations should also be suggested. For example, with the artificial ultrasound system, do we expect that the moths will habituate to this and overcome the method? Addition of this kind of analysis will profit this work (much as we need to assess development of pesticide resistance).

c) What are future research plans, and will it include a strategy to manufacture the equipment at lower costs so that farmers can better afford the technologies? Several issues are unsolved or need expensive infrastructure, e.g. electricity in the field. The rating is: **A – good quality and minor revision needed.**

NARO responses to the comments of the Evaluation Committee

a) Patents have been filed in relation to the technique used to attract natural enemies by LED radiation and the technique used to repel lepidopteran pests by ultrasound. Some patents have already been obtained. We have been working on commercializing these techniques by collaborating with some private enterprises in a project funded by the Cabinet Office, and we are closing in on the goal. We are also considering commercializing techniques used to control pests on tea plant using blue LED light. With regard to the effects on non-target organisms, we will avoid risks based on basic knowledge on visual and auditory senses.

b) With regard to the ultrasonic technique, we have already conducted studies on how to prevent reduction in its effect due to habituation. Furthermore, pulse patterns that less likely cause habituation at the auditory nerve and behavior levels have been identified and used in the device. This technique exploits the avoidance behavior exhibited by moths in response to ultrasonic pulses emitted by bats, their natural enemies, during predation. Therefore, we believe that it is unlikely the moths will overcome this technique in a long term.

c) As commented in a), research on the promotion of the practical application of the device at farms is in progress. In Japan, vegetable fields are commonly situated near houses, and electric anti-frost fans are widely used in tea plantations. Therefore, the device can be introduced to fields to which electricity can be supplied without special infrastructure development. Currently, we are developing an ultrasonic device and LED devices that use commercially available batteries and low power consumption components. Our plan is to introduce these systems to regions where electricity is not easily secured.

Project 6A Discovery of a plant resistance inducer with a new mode of action and development of new biological agents

Development of new biological agents is extremely important as pests and pathogens are increasing developing resistance to agrochemicals, and we recognize the need to protect the environment. Stimulating the natural plant tolerance to pathogens applying natural substances and/or microorganisms has an increasing potential for an environmentally friendly control of diseases. The presented projects aimed at control of wilt disease soil-borne diseases and pepper mild mottle virus (PMMoV).

The research in this project appears to be an extension of work that was conducted in other laboratories more than 20 years ago to identify chemical inducers of innate immunity, with the goal to provide resistance to a wide range of fungal and bacterial pathogen. Some products currently on the market provide partial resistance to some pathogens but not others. Discovery of L-His as an inducer is interesting and is worthy of further research to identify the mechanisms of resistance and potential to develop a commercial product. a) It remains to be seen whether or not this approach is viable as a means to a commercial product.

Efforts to develop a cross-protecting strain of PMMoV has gotten underway: the approach taken is not novel or unique, but is likely to produce a mild strain of the virus that provides pathogen suppression. b) It is

disappointing to see that NARO is not engaged in developing plant resistance, either through plant breeding or via biotechnology, including pathogen derived resistance, RNAi, or other technologies.

c) The team is encouraged to develop a time line for developing novel and durable strategies for increasing host immunity. The rating is: **A – good quality and minor revision needed.**

NARO responses to the comments of the Evaluation Committee

- a) We are ultimately aiming to develop agricultural chemicals that induce resistance. In Japan, for a new agricultural chemical to be commercialized, it has to pass a control effect test, toxicology test, safety assessment, and other requirements, which is time consuming and expensive. Currently, we are clearing these hurdles individually. Our target is to secure registration within five years.
- b) Although not discussed here owing to time and other constraints, other centers and departments of the NARO are currently developing pest-resistant varieties of cereals, vegetables, and other crops; and disease- and insect-resistant crops using genetic engineering.
- c) We will create a process chart based on the feedback we have received.

Project 6B New chemical research for the control of insect pests using semiochemicals

Pheromone-based mating disruption is developed to control the white grub beetle and the Japanese mealy bug. The use of pheromones in agriculture has never reached its potential. However, this work in identifying effective blends and deploying them with appropriate and relatively easy to use dispensers should certainly overcome many of the components that held back use of pheromones. These methods have strong potential to address reduction of pesticide use in Japan. Continued investment in discovery and development of commercial dispensing systems is well warranted.

a) However, it should be mentioned that mating disruption is not a good solution for individual farmers but needs all farmers to take part. Area-wide control may be hampered by structure of small fields and large number of farmers which need to be motivated to attend mating disruption program. The rating is: **A – good quality and minor revision needed.**

NARO responses to the comments of the Evaluation Committee

- a) As you pointed out, a sufficiently large area has to be treated to achieve stable control effect by mating disruption. Therefore, it is recommended that a region-wide collective pest control should be carried out. We will promote the mating disruption technique among researchers at agricultural research institutes who are offering technical guidance to producers. Furthermore, through tours and briefing sessions for farm management bodies, we will promote the importance of collective pest control and the possibility of adding value to products using mating disruption.