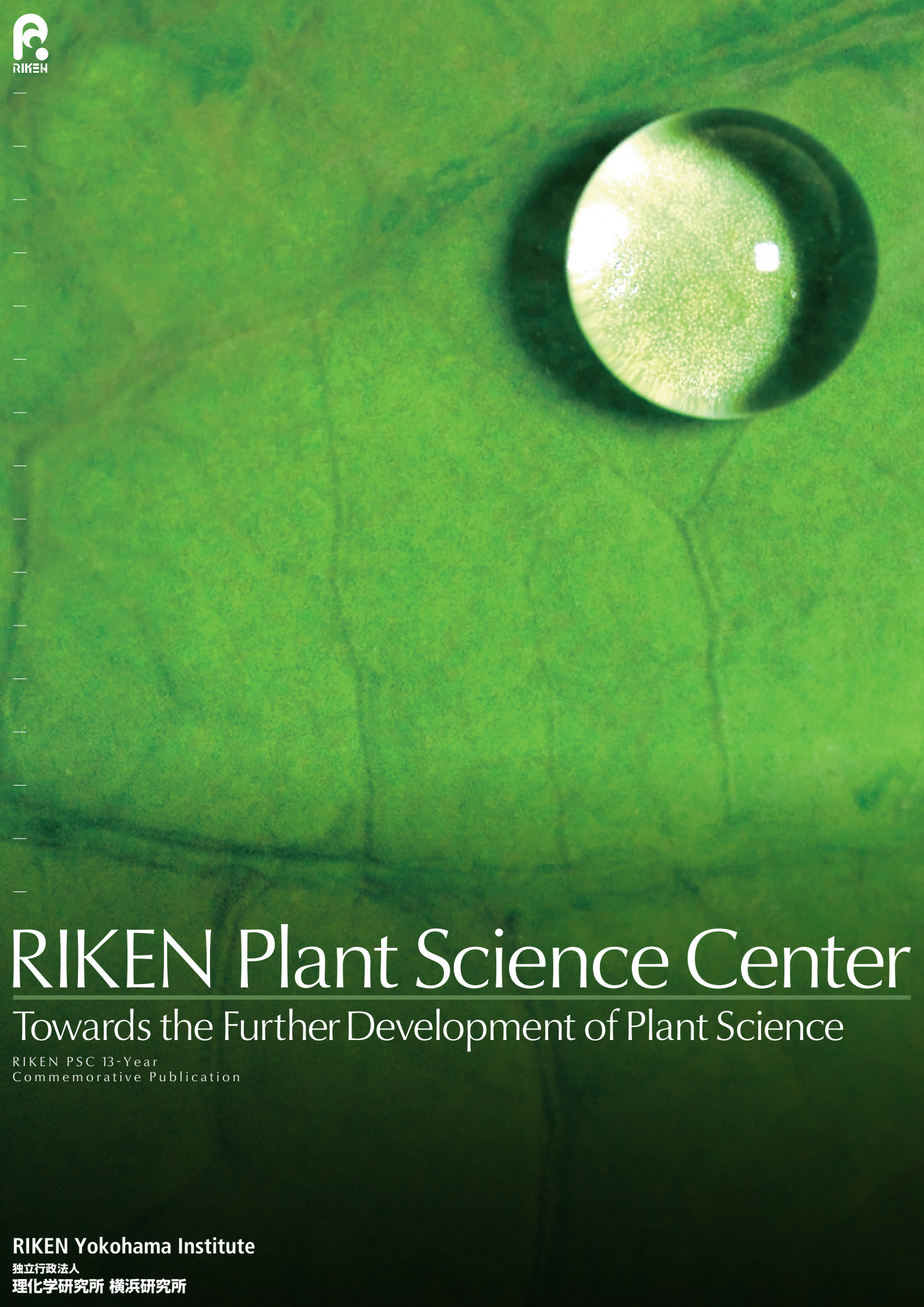

RIKEN Plant Science Center

Towards the Further Development of Plant Science

RIKEN PSC 13-Year
Commemorative Publication

RIKEN Yokohama Institute
独立行政法人
理化学研究所 横浜研究所

RIKEN Plant Science Center

Towards the Further Development of Plant Science

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Commemorative Publication

RIKEN Yokohama Institute

Contents

Foreword

For the Further Development of Plant Science

Akihiro Fujita
[Director, RIKEN Yokohama Institute]

The RIKEN Yokohama Institute was established in 2000 as a major Japanese research center in the life sciences.
Although its history spans a mere 13 years, the research that it conducts is at the world's highest levels. Moreover, it not only has strong ties with other institutes inside the RIKEN organization; its relations with outside research institutions, universities and corporations are continuing to deepen and expand.
The Plant Science Center, like the Yokohama Institute, was founded in 2000. In recent years, society's expectations regarding the contributions that can be made, through scientifically elucidating the functions of plants, to solving environmental problems and modern social problems have grown considerably.
As part of RIKEN's 3rd Medium-Term Plan, set to begin in 2013, the Plant Science Center will make a new start when it merges with chemical biology and catalytic chemistry projects of Advance Science Institutes at Wako to start a new Center for Sustainable Resource Science.
This pamphlet looks back at the Plant Science Center's history over these past 13 years from various perspectives, and also seeks to look ahead at the future development of plant science research.
I would like to sincerely thank you for your past support of our activities, and ask that you please continue to provide us with your valued understanding and cooperation in the future.

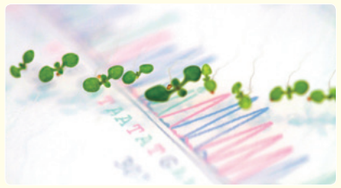
The 13 years of the Plant Science Center

Kazuo Shinozaki
[Director, RIKEN Plant Science Center]

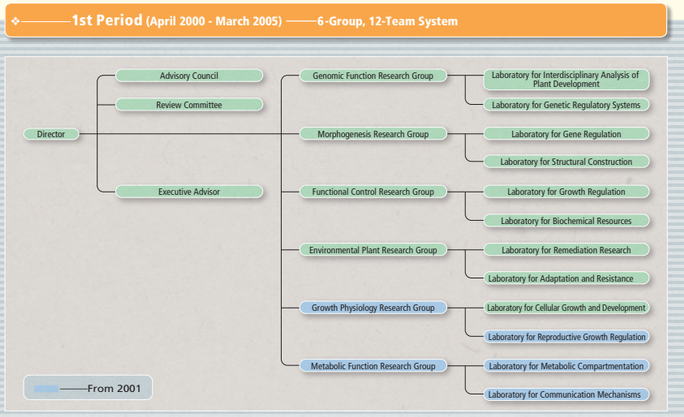
The Plant Science Center was established in 2000 as part of the Millennium Project of Japan.
In its first period, in parallel with genome sequencing of rice, the Center elucidated key functions of model plants like Arabidopsis under the guidance of previous Center Director Tatsuo Sugiyama. Based on the motto, "Learn from plants, utilize plants," considerable progress was achieved in basic plant research cooperated with the Rice Genome Research Program under the Ministry of Agriculture, Forestry and Fisheries.
In its second period, the Center began a new project to analyze the functions of plant genes related to "improving the quantitative and qualitative productivity of plants," and initiated metabolome research, leading to the establishment of world-leading research platform.
It published numerous highly-cited papers and developed into a world-class research institution. Society's expectations for the Center to contribute, as a social outcomes of plant science research, to solving not only food problems but also environmental and energy problems have also become sizable in recent years. The activities which the Center is now being asked to conduct cover a broad range, from research on plant genome functions to applying the results of research to agriculture and industry by cooperating with other fields.
In 2013, we will make a new start as the Center for Sustainable Resource Science, an organization combining plant science, chemical biology and catalytic chemistry.
We will aim to create, and to use and apply, renewable resources for sustainable production.
Based on the Plant Science Center's 13 years of experience and achievements, we look forward to undertaking new challenges. I would like to ask your continuous guidance and encouragement.

Overview of the Plant Science Center

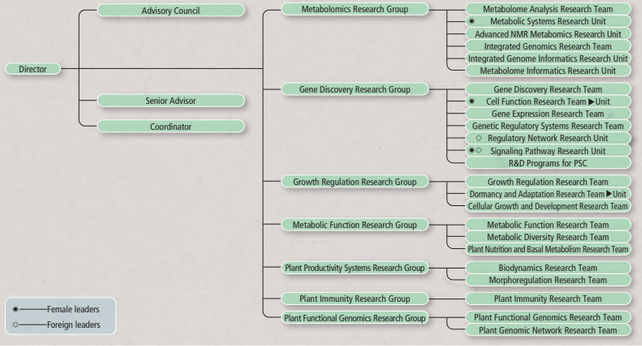
❖The Plant Science Center (PSC) was established in 2000 as a part of the national government's Millennium Project.
In the five years of its first period, PSC cooperated with Japanese and foreign research institutions and was able to produce various noteworthy results, including the synthesis of plant hormones and the distribution of related information;an integration of chemistry, biochemistry and molecular genetics; and genome information and resources for Arabidopsis.
❖In the second period, which began in 2005, PSC undertook efforts – based on functional genomics (transcriptomics, proteomics, metabolomics, etc.) that used model plants –to understand plant growth regulation, morphogenesis, photosynthesis, metabolism, environmental responses and other phenomena as an overall system. We also searched for genes related to increasing food production and improving health, and promoted basic research on the functions by which plants produce their various substances.
❖These and other research results from PSC in past 13 years have been highly regarded by plant research institutions throughout the world. In the future they will continue to be used to safeguard food, health and the environment, and will contribute to building a sustainable society for the coming generation.



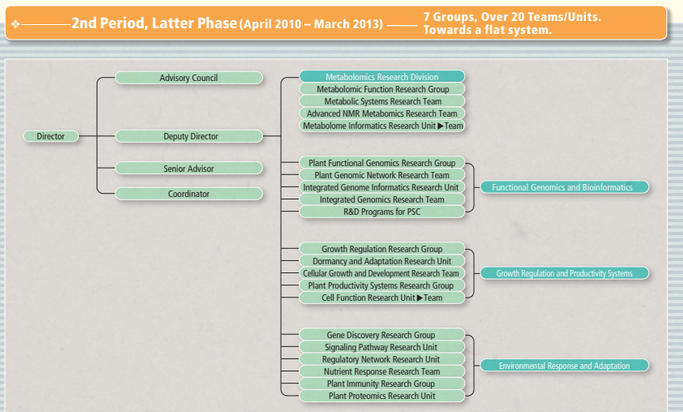
❖1st Period (April 2000 - March 2005) ——6-Group, 12-Team System



❖2nd Period, Initial Phase (April 2005 – March 2010) —— 7-Group, 20-Team/Unit System. First female leaders and foreign leaders.



❖2nd Period, Latter Phase (April 2010 – March 2013) —— 7 Groups, Over 20 Teams/Units. Towards a flat system.

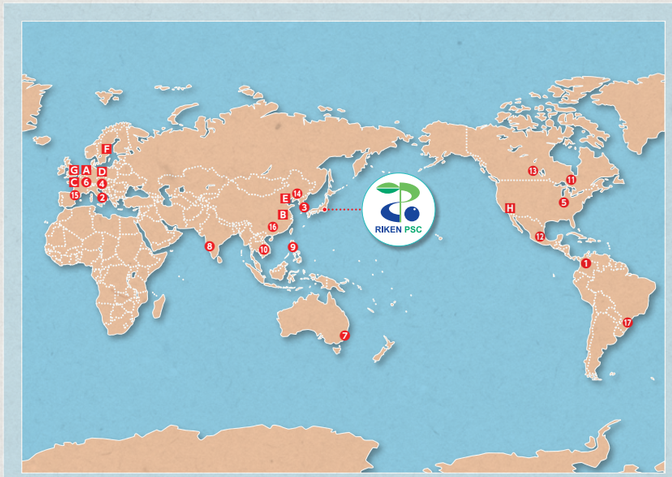


❖Network of the Plant Science Center

[Leading-edge Research Infrastructure Program Japan
Advanced Plant Science Research Network]
- Tohoku University
- University of Tsukuba
- The University of Tokyo
- RIKEN Plant Science Center
- Nagoya University
- National Institute for Basic Biology
- Nara Institute of Science and Technology
- Kyoto University
- Okayama University

[**Domestic Collaboration**]
- **Building a Metabolomics Research Platform**
  - Kazusa DNA Research Institute
  - Institute for Advanced Biosciences, Keio University
- **Research on Wheat**
  - Kihara Institute for Biological Research, Yokohama City University
- **Research on Rice**
  - National Institute of Agrobiological Sciences
  - Japan International Research Center for Agricultural Sciences
  - Okayama Prefectural Technology Center for Agriculture, Forestry, and Fisheries, Research Institute for Biological Sciences
- **Disposal of Waste Containing Heavy Metal with Moss**
  - DOWA Holdings Co., Ltd.
- **Plant Genome Science and Biotechnology for Increase in Biomass**
  - Forestry and Forest Products Research Institute

[**Partner Schools**]
- Yokohama City University
  Kihara Institute for Biological Research
- Yokohama City University
  Graduate School of Nanobioscience
- University of Tsukuba
  Graduate School of Life and Environmental Science
- Tokyo Metropolitan University
  Graduate School of Science and Engineering
- Nagoya University
  Graduate School of Bioagricultural Sciences
- The University of Tokyo
  Graduate School of Sciences
- Tohoku University
  Graduate School of Agricultural Science
- Chiba University
  Graduate School of Advanced Integration Science



[**International Collaboration — Collaborative Research**]

Collaborative Research Agreement for Each Research Laboratory

1. International Center for Tropical Agriculture (CIAT), Colombia (2006-)
2. University of Erlangen-Nuremberg (FAU), Germany (2007-)
3. Korea Advanced Institute of Science and Technology (KAIST), Korea (2007-)
4. Max Planck Institute for Chemical Ecology, Germany (2007-)
5. Michigan State University, USA (2008-)
6. University of Karlsruhe, Germany (2008-)
7. Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia (2008-)
8. Rajiv Gandhi Centre for Biotechnology (RGCB), India (2009-)
9. International Rice Research Institute (IRRI), Philippines (2008-)
10. Mahidol University, Thailand (2009-)
11. Trent University, Canada (2009-)
12. International Maize and Wheat Improvement Center (CIMMYT), Mexico (2008-)
13. Phenomenome Discoveries Inc., Canada (2005-)
14. China Agricultural University, China (2007-)
15. French National Institute for Agricultural Research (INRA), France (2011-)
16. Institute of Agricultural Genetics, Vietnam (2011-)
17. The Brazilian Agricultural Research Corporation, Brazil (2012-)

[**International Collaboration — Memorandum of Understanding for Research Collaboration**]

Research Exchange and Research Collaboration as a Research Center

- A Max Planck Institute of Molecular Plant Physiology, Germany (2005-)
- B College of Forest and Environment, Nanjing Forestry University, China (2007-)
- C Flanders Institute for Biotechnology (VIB), Belgium (2007-)
- D Leibniz Institute of Plant Biochemistry, Germany (2007-)
- E College of Biological Sciences, China Agricultural University, China (2007-)
- F Umea Plant Science Centre, Sweden (2010-)
- G John Innes Centre and the Sainsbury Laboratory, UK (2007-)
- H Division of Biological Sciences, The University of California, San Diego, USA (2010-)

The 13 Years of the Plant Science Center

*Mention of the location has been omitted for events held at the RIKEN Yokohama Institute.

Plant Science Center [PSC]

2000

1st PSC Symposium
November 1, at RIKEN Wako Campus

Opening ceremony for Yokohama Institute
November 6

22nd RIKEN Science Symposium
November 6, at Pacifico Yokohama Conference Center

Symposium of National Projects for Plant Science
- Plant Gene Project of the Japan Society for the Promotion of Science
- RIKEN Plant Science Center
- Ministry of Agriculture, Forestry and Fisheries˙Rice Genome Project

December 6, at Cross Tower Hall (Tokyo)

PI List [1st Period]

[Genomic Function Research Group]
Kiyotaka OKADA
[Laboratory for Interdisciplinary Analysis of Plant Development] — **Takuji WADA**
[Laboratory for Genetic Regulatory Systems]
Tatsuya SAKAI
[Morphogenesis Research Group]
Hiroo FUKUDA
[Laboratory for Gene Regulation]
Taku DEMURA
[Laboratory for Structural Construction]
Ken MATSUOKA
[Functional Control Research Group]
Shigeo YOSHIDA
[Laboratory for Biochemical Resources]
Toshiya MURANAKA

[Environmental Plant Research Group]
Isamu YAMAGUCHI
[Laboratory for Adaptation and Resistance]
Hiroshi HAMAMOTO
[Growth Physiology Research Group]
Yuji KAMIYA
[Laboratory for Reproductive Growth Regulation] — **Eiji NAMBARA**
[Metabolic Function Research Group]
Tomoyuki YAMAYA
[Laboratory for Metabolic Compartmentation]
Hideki TAKAHASHI
[Laboratory for Communication Mechanisms]
Hitoshi SAKAKIBARA

2001

RIKEN Open House 2001
April 21

2nd PSC International Symposium "Plant Morphogenesis"
November 26-27, at the University of Tokyo, Yayoi Auditorium

Symposium of National Projects for Plant Science
- Plant Genetics Research Promotion Committee, JSPS Research for the Future Program
- RIKEN Plant Science Center
- Ministry of Agriculture, Forestry and Fisheries˙Rice Genome Project

December 3-4, at Yasuda Life Hall

2002

Each laboratory of PSC moves from RIKEN Wako Campus and Kyoto University to RIKNE Yokohama Institute.
April

Joint symposium of PSC and Grant-in-Aid for Scientific Research on Priority Areas "Signal perception and transduction in Higher Plants"
April 26, at RIKEN Wako Campus

Joint Meeting between Max-Planck-Institute of Molecular Plant Physiology and PSC "Nutrients, Metabolism and Development"
May 27-28, at Max-Planck Golm Institute (Golm, Germany)

RIKEN Yokohama Institute Open House 2002
July 20

To commemorate the consolidation of the Yokohama Institute, a gingko tree (whose sperm is first discovered) is planted by PSC Director and Mayor Nakata of Yokohama.

PSC Retreat
October 8-9, at Kazusa Akademia Park

France-Japan Binational Symposium on Plant Biology 2002 "Communication of regulatory signals among cellular compartmentation in plant metabolisms"
October 29-31, at Nara Prefectural New Public Hall

3rd PSC International Symposium "Biosyntheses of plant hormones and beyond"
November 18-19, at RIKEN Wako Campus

Joint Meeting of Millennium Plant Science Research Projects
December 2, at Yasuda Life Hall

Main Events Outside the Center
[RIKEN history and important domestic /foreign news]

2000

Apr Opening of RIKEN Yokohama Institute
RIKEN Plant Science Center (4 groups) and RIKEN SNP Research Center established as part of Millennium Project.
RIKEN Center for Developmental Biology established.
Name of Tsukuba Life Science Center changed to RIKEN Tsukuba Institute

Aug Sydney Olympics

Dec Dr. Hideki Shirakawa receives Nobel Prize.

2001

Jan RIKEN BioResource Center established (in Tsukuba Institute).

Apr Start of Koizumi administration

Jul RIKEN Research Center for Allergy and Immunology established(in Yokohama Institute).

Sep 9/11 terrorist attacks

Oct Dr. Ryoji Noyori wins Nobel Prize in Chemistry.

2002

Apr RIKEN Discovery Research Institute established
RIKEN Kobe Institute established

Jun 17th World Cup Tournament, jointly hosted by Japan and South Korea.

Dec Drs. Masatoshi Koshiba and Koichi Tanaka receive Nobel Prizes.

2003

1st Advisory Council Meeting
March 12-14

RIKEN Yokohama Institute Open House 2003
June 14

Industry-Government-Academia Symposium on Plant Science "Bioscience that learns from plants and utilizes them"
August 25, at Nagoya University Graduate School of Bioagricultural Sciences

13th Dolichol and Isoprenoid Workshop Regular research meeting
September 4

PSC International Symposium 2003 "Plant Science and the Environment"
November 10-11

Arabidopsis Workshop 2003
November 12

PSC Science Retreat
November 27

Joint Meeting of Millennium Plant Science Research Projects
- Plant Genetics Research Promotion Committee, JSPS research for the Future Program
- RIKEN Plant Science Center
- Ministry of Agriculture, Forestry and Fisheries˙Rice Genome Project

December 4-5, at Yasuda Life Hall

2004

2nd Advisory Council Meeting
March

Public Lecture "Plant Power Supporting Better Life and Living – Research Results from the Millennium Project"
May 8, at Yayoi Auditorium, The University of Tokyo Faculty of Agriculture

RIKEN Yokohama Institute Open House 2004
June 26

International Workshop on Tobacco BY-2 Cells
September 14-16

Joint Meeting of Millennium Plant Science Research Projects
December 2, at Kokuyo Hall (Shinagawa)

2005

Start of PSC˙s 2nd period (5 groups)
April

6th International Workshop on Plant Sulfur Metabolism
May 17-21, at Kazusa Akademia Center

Deciding on PSC˙s logo
May

The research entitled "Rapid Identification of Useful Traits Using Rice Full-Length cDNAs" started, being supported by Special Coordination Funds for Promoting Science and Technology
May

Signed letter of intent for metabolome research with Keio University
June 1

RIKEN Yokohama Institute Open House 2005
June 25

France-Japan Workshop on Plant Sciences 2005 "Cellular signaling and development"
September 25-29, at Sofitel Toulouse Centre, Toulouse, France

Start of Pant Immunity Research Group
October 1

Protein Phosphorylation in Plant Signaling
October 20-21, at Tsukuba International Congress Center (Epochal Tsukuba)

Functional Network of Transcription Factors in Plants
November 16-17, at Tsukuba International Congress Center (Epochal Tsukuba)

Plant Science Research Project Symposium "Green Techno-Planning: Aiming to Comprehensively Improve Plant Productivity"
- National Institute of Agrobiological Sciences
- RIKEN Plant Science Center
- Network of University Plant Scientists

December 2, at Kokuyo Hall

2006

Joint seminar with Max Planck Institute of Molecular Plant Physiology (Golm, Germany)
March 16-17

Plant Functional Genomics Research Group moves from Genomic Sciences Research Center to PSC.
April 1

3rd Advisory Council Meeting
April 19-21

Metabolomics Research Group achieves top ranking in plant biotechnology field for number of papers cited.
April

PSC Retreat
May 12

RIKEN Yokohama Institute Open House
June 24

Special Seminar on Plant Metabolism and Metabolome
August 1

Plant Science Symposium "Towards a General Understanding of Plants and Improving Plant Productivity"
- Network of University Plant Scientists
- National Institute of Agrobiological Sciences
- RIKEN Plant Science Center

December 1, at Kokuyo Hall

Outreach lecture on "Rapid Identification of Useful Traits Using Rice Full-Length cDNAs"
December 23, at Sanyo Newspaper˙s Santa Hall

2003

Sep RIKEN˙s status as a public corporation, terminated in preparation for becoming an Independent Administrative Institution

Oct RIKEN reorganaized as an Independent Administrative Institution
First President: Ryoji NOYORI

2004

Sep RIKEN announces discovery of 113th chemical element.

Aug Athens Olympics

Dec Sumatra earthquake

2005

Mar Millennium Genome Project ends.

Apr RIKEN Center for Intellectual Property Strategies established

Jul RIKEN Center of Research Network for Infectious Diseases established

Sep RIKEN Molecular Imaging Research Program launched

Oct RIKEN Spring-8 Center established

2006

Jan RIKEN Next-Generation Supercomputer R&D Center established
Singapore Representative Office opened.

Mar XFEL Project office opened

Apr RIKEN Nishina Center for Accelerator-Based Science established

Sep Start of Abe administration

Oct Emperor and Empress visit RIKEN.

Plant Science Center [PSC]

2007

PSC International Symposium —Trends in Plant Hormones—
March 1-2

Signed memorandum of understanding for research cooperation with Nanjing Forestry University, China
March 14

Memorial symposium of Kihara Institute for Biological Research "Edible Medicine" co-hosted with Yokohama City University's Kihara Institute for Biological Research
June 1

RIKEN Yokohama Institute Open House
June 23

13th Seminar by RIKEN Friends in Industry "The relationship between plant science and industry/the environment"
November 1, at the Industry Club of Japan Building

Outreach lecture on Rapid Identification of Useful Traits Using Rice Full-Length cDNAs "Searching for Unknown Gene Functions in Plants"
November 3, at Tsukuba International Congress Center (Epochal Tsukuba)

JSPS/JST Joint International Symposium "Towards the Advanced Use of African Resources in Plant Science"
November 20

Plant Science Symposium "The Development of Plant Science"
- National Insitute of Agrobiological Sciences
- RIKEN Plant Science Center
- Network of University Plant Scientists
- Forestry and Forest Products Research Institute

December 3, at Kokuyo Hall

Arabidopsis Workshop 2007
December 10

Super Science High School Program for Plant Science as an outreach activity of "Rapid Identification of Useful Traits Using Rice Full-Length cDNAs"
December 18, at Tamasima High School in Okayama Pref.

2008

UK-Japan Workshop: Frontiers in Plant Post-Genomics
January 18

90th Sustainable Humanosphere Symposium "Tree Biotechnology that Will Open up the Future"
February 18

Arabidopsis mutant in space! "HMG1 mutant" launched aboard the space shuttle Endeavor
March 11

Japan-Korea Symposium
June 9-10

Introductory Workshop on RIKEN Genetic Transformation Network
June 16

RIKEN Yokohama Institute Open House
July 5

5th International Conference on Plant Metabolomics
July 15-18, at Pacifico Yokohama (Annex Hall)

PSC's catchphrase decided: "Cultivating Tomorrow"
July

Joint Retreat (RIKEN PSC, Kazusa DNA Research Institute, Kihara Institute for Biological Research)
October 2-3, at Kazusa Akademia Park

Plant Hormone Technology Workshop
October 28

3rd Metabolome Symposium
October 30 – November 1, at Keio University Institute for Advanced Biosciences

4th Advisory Council Meeting
November 25-27

Japanese Society for Plant Cell and Molecular Biology, Public Symposium "Food, Environment, Health and Energy: the Power and Hope of Plant Biotechnology"
November 29, at Otemachi Sankei Plaza

Plant Science Symposium "Utilizing Plant Power for the Future of Humanity"
December 1, at Kokuyo Hall

2009

RIKEN Science Lecture
February 28, at Marunouchi Building Hall

Signed MOU for research cooperation with College of Biological Sciences, China Agricultural University.
May 19

RIKEN Yokohama Institute Open House
July 3

PSC Retreat
September 16

4th Metabolome Symposium
November 18-19, at Yokohama Science Frontier High School

Japanese Society for Plant Cell and Molecular Biology, Public Symposium "The Familiar Power of Plant Biotechnology"
November 21, at Otemachi Sankei Plaza

Plant Science Symposium "Eliciting the Potential of Plant Science: Aiming to Achieve Made-in-Japan GM Plants"
December 1, at Kokuyo Hall

Main Events Outside the Center

[RIKEN history and important domestic /foreign news]

2007

Apr RIKEN Molecular Imaging Research Program launched at Kobe Institute.

Sep Start of Fukuda administration

2008

Mar Genomic Sciences Research Center closed.

Apr Launching of second midterm plan Established Advanced Science Institute, Omics Science Center, Systems and Structural Biology Center, and Bioinformatics and Systems Engineering Division. Name of SNP Research Center changed to Center for Genomic Medicine.

Aug Beijing Olympics

Sep Lehman shock. Start of Aso administration

Oct RIKEN Center for Molecular Imaging Science established

Dec Drs. Makoto Kobayashi, Toshihide Maskawa, Yoichiro Nambu and Osamu Shimomura receive Nobel Prize.

2009

Sep Change of government: start of Hatoyama administration

Nov RIKEN's activities become the subject of a review by the government budget-screening process.

2010

"Symposium for Green Innovation Utilizing Plants"
May 29, at Science Council of Japan Lecture Hall

21st International Conference on Arabidopsis Research
June 6-10, at Pacifico Yokohama

Agenda of VIB-PSC meeting
June 10

ICAR2010 Satellite Workshop
June 11-12

RIKEN Yokohama Institute Open House
July 3

1st International Symposium on the Nitrogen Nutrition of Plants
July 26-30, at Inuyama International Sightseeing Center (Freude Hall)

RIKEN Yokohama Science Café "How Plants Live Tenaciously"
August 28, at Yokohama City Central Library

PSC Retreat
October 2

International Symposium on Plant Productivity
October 24-26, at Trent University, Peterborough, Ontario, Canada

2010 Plant Electron Microscopy Workshop forJunior Scientists
November 18-19

Plant Science Symposium "A New Plant Science Geared to Green Innovation"
December 1, at Kokuyo Hall

2011

International Plant RNA Workshop 2011
June 20-21

5th Advisory Council Meeting
July 19-21

2011 Joint Retreat (RIKEN PSC, BMEP, Kihara Institute for Biological Research)
September 29-30, at RIKEN Yokohama Institute and Kihara Institute for Biological Research, Yokohama City University

RIKEN Yokohama Institute Open House
October 4

2011RIKEN Chemical Biology Symposium "Next-Generation Tools for Molecular Target Discovery"
October 20-21, at RIKEN Wako Campus

2011 Plant Electron Microscopy Workshop for Junior Scientists
November 21-22

Plant Science Symposium "Plant Science – Contributing to Solving Food, Energy and Environmental Problems"
December 2, at Kokuyo Hall

Joint Workshop of the Japan Advanced Plant Science Research Network and the Network of the Center of Carbon Dioxide Resource Studies in Plants
December 12, at the University of Tokyo, Faculty of Science Building No. 2 Auditorium

RIKEN Science Seminar V "Secrets of 400 Million Years – Beauty of Japan, Power of Mosses"
December 16, at Roppongi Academy Hills

2012

2nd Meeting for Young Scientists "Synthetic Biology, Aiming to Create New Materials"
January 27

Fascination of Plants Day (International Plant Day)
(April 21 – June 22), at RIKEN Wako Institute, etc.

International Symposium of Plant Science "Plant Science for the Future"
November 20

Plant Science Symposium "Expectations for Leading-Edge Plant Science Research"
December 3, at Kokuyo Hall

PI List [2nd Period, Initial Phase]

[Metabolomics Research Group]
Kazuki SAITO
[Metabolic Systems Research Unit]
Masami Yokota HIRAI
[Advanced NMR Metabomics Research Unit]
Jun KIKUCHI
[Integrated Genomics Research Team]
Yukihisa SHIMADA
[Integrated Genome Informatics Research Unit]
Tetsuya SAKURAI
[Metabolome Informatics Research Unit]
Masanori ARITA
[Gene Discovery Research Group]
Kazuo SHINOZAKI

[Cell Function Research Team]
Ken MATSUOKA
[Gene Expression Research Team]
Takuji WADA
[Genetic Regulatory Systems Research Team]
Tatsuya SAKAI
[Growth Regulation Research Group]
Yuji KAMIYA
[Dormancy and Adaptation Research Team]
Eiji NAMBARA
[Cellular Growth and Development Research Team]
Shinjiro YAMAGUCHI
[Metabolic Diversity Research Team]
Toshiya MURANAKA

[Plant Nutrition and Basal Metabolism Research Team]
Hideki TAKAHASHI
[Plant Productivity Systems Research Group]
Hitoshi SAKAKIBARA
[Morphoregulation Research Team]
Taku DEMURA
[Plant Immunity Research Group]
Ken SHIRASU
[Plant Functional Genomics Research Group]
Minami MATSUI
[Plant Genomic Network Research Team]
Motoaki SEKI

2010

Apr RIKEN Research Cluster for Innovation established
Start of RIKEN Biomass Engineering Program (BMEP)
Japanese name for RIKEN Center of Research Network for Infectious Diseases changed.

Jun Start of Kan administration

Jul RIKEN Advanced Institute for Computational Science established

Dec Drs. Akira Suzuki and Eiichi Negishi receive Nobel Prize.

2011

Mar Great East Japan Earthquake

Apr RIKEN Quantitative Biology Center established
RIKEN HPCI Program for Computational Life Sciences established

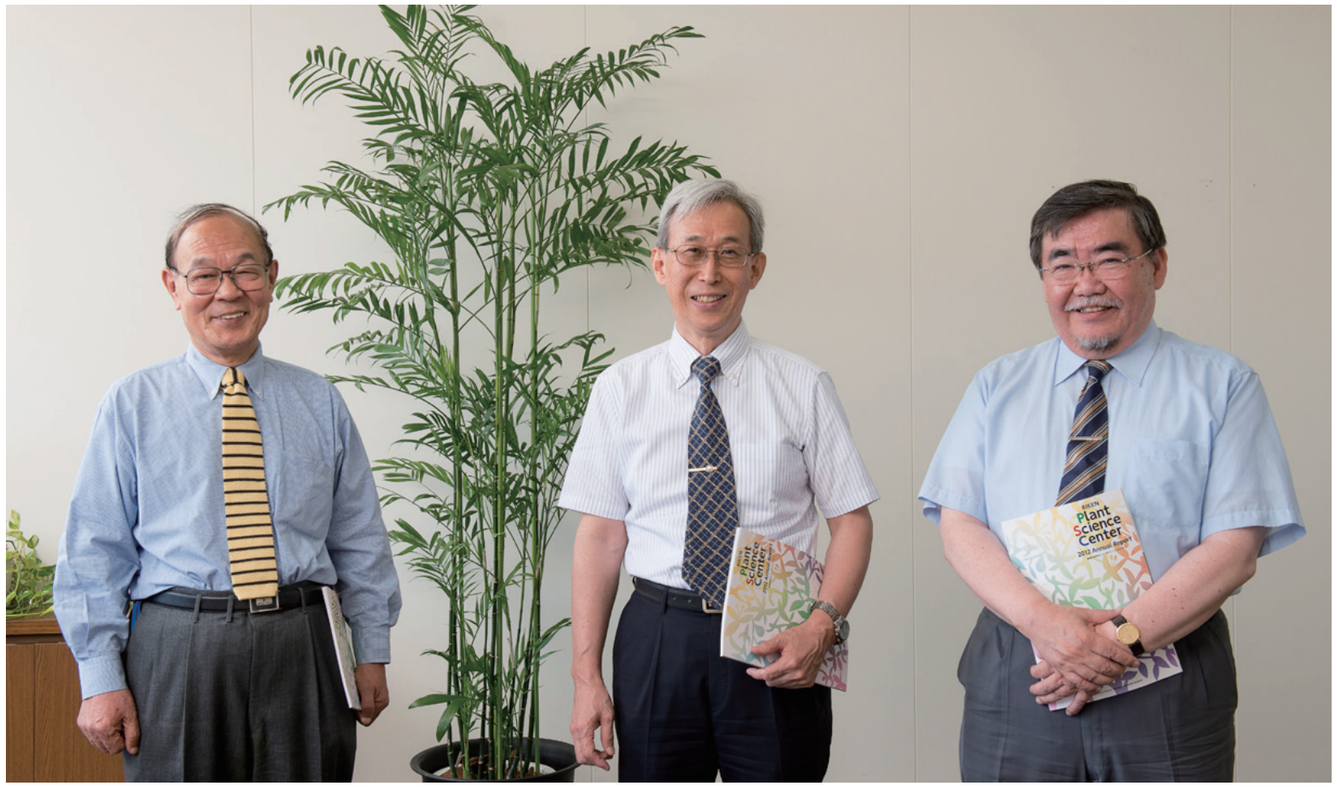
2012

Jul London Olympics

Dec Dr. Shinya Yamanaka receives Nobel Prize.

Looking Back at the Plant Science Center's 13 Years

**In the first period, we promoted projects under the motto, "Learn from plants, utilize plants."
In the second period, we focused on improving plant productivity and
built foundations for metabolome analysis.
Then we entered a new phase related to green innovation.
Three researchers who nurtured and led the Plant Science Center discuss its 13 years
of history and future prospects.**



The Plant Science Center —— Progressing Together with the Development of Plant Science

Shinozaki: The RIKEN Plant Science Center (PSC) has progressed extensively in the 13 years since it was established in 2000. During that time, plant science has also progressed, and I feel that PSC has contributed to leading the way. The Center was founded at a time when new developments in plant science were burgeoning. For example, gene recombination technology was advancing, as was functional genomics that used model plants. But before getting to that, I would like to ask Dr. Yoshida to talk about the background to the founding of PSC.

Yoshida: Up to 1999, the year before the founding, the International Frontier Research System, a unique research system centered around limited-term contract researchers – Japan's first such system – was in operation at RIKEN. In the plant research that, based on the theme of biological homeostasis, was carried out under that system, attention was focused on two areas in particular: phytochrome and plant hormone function. In connection with that, the national government wanted to introduce an innovative research system for science and technology at the turn of the new century. We then suggested to the government that Japanese plant science should concentrate on elucidating plant functions as its primary undertaking.

Shinozaki: This was related to the Millennium Project, which became the catalyst for the birth of PSC. PSC took charge of the part of the Project related to functional genomics of model plants like *Arabidopsis*. I remember that we started off by teaming up with the Ministry of Agriculture, Forestry and Fisheries to research the rice genome. At the time of the founding, PSC's first director, Dr. Sugiyama, had some major headaches, if I remember correctly. How was the situation back then?

Sugiyama: For the Millennium Project, we were asked to elucidate the genome functions of model plants other than rice, and to contribute to the development of high-function crops and low-pesticide crops. We gathered superior personnel by a top-down method in which the center director chose the group directors, the group directors chose the team leaders, and the group directors and team leaders chose their respective staffs. However, these units were located in different places, and I was faced with the difficult task of creating, in a short span of five years, a situation where we could all tackle a single objective with a sense of unity. At any rate, two groups were housed at the Brain Science Institute's Building, and three groups were in the Bioscience Building and the Central Research Building on the Wako campus. We also had a group that was located in part of the Botanical Garden of the Kyoto University, Faculty of Science.

Under those conditions, the individual teams and groups held working lunches to which I was invited; they increased the joint seminars; and they otherwise consciously tried to maintain a sense of unity. For that reason alone we ardently wanted to consolidate PSC. And finally, in 2002, we succeeded in bringing everyone together at this Yokohama Institute. The first thing I did after we moved to Yokohama was to establish a shared facility for growing plants that would become our lifeline.

The First All-Japan System

Shinozaki: In the first period Dr. Sugiyama and group directors carried out projects under the motto, "Learn from plants, utilize plants. "PSC was Japan's premier institution in the plant sciences, so it was possible to plan joint conferences with the Ministry of Agriculture, Forestry and Fisheries and with universities and others. But promoting projects with the all-Japan system had its difficulties, I think.

Sugiyama: We confronted the research head-on. What made that possible was our excellent staff. We were also blessed with public funding. As you know, it's close to impossible to provide a succinct definition of what a living organism is. But what I thought we should aim to research, based on genome science, was the distinctive attributes of living organisms, particularly plants.

Those three attributes are photosynthesis, which functions as the primary producer of the organic compounds on which all earthly life relies; morphogenesis, by which plants grow towards light and thereby defy gravity; and immobility. We put our focus on unraveling the underlying molecular mechanisms of those three attributes. However, those days were a time of confusion. It was when RIKEN became an independent administrative institution, and when the Science and Technology Agency merged with the Ministry of Education. We therefore took a two-pronged approach. We encouraged young people to focus on fundamental and basic research linked to the future, while senior researchers concentrated on utilizing plants by using their elucidated molecular mechanisms.

As a result, we were fortunately able to create a sense of unity, a kind of centripetal force, in the first period. However, no major national policy was issued for Japanese plant researchers, so I think they were lacking in a spirit that would have brought them together into a kind of all-Japan team. To overcome that situation, we decided to go beyond what the government agencies were providing and create opportunities for the researchers to become united – to create a setting where they could report their research results and exchange information.

Shinozaki: You mean the Plant Science Symposium held in December, right? This annual event for reporting research still exists. I feel it is one of the most representative activities of the plant research in the all-Japan system.

Sugiyama: At that time, I attended meetings of expert committees of the Cabinet Office and so on. But the committee members had serious questions about the vertical structure of government agencies and the concomitant lack of coordination between them. Creating an all-Japan system for plants under those circumstances was a major achievement, I think.

Shinozaki: In research, RIKEN is especially strong in the plant sciences related to chemistry; its plant hormone research and metabolism research have made great strides. On the other hand, researchers who specialize in molecular genetic research on *Arabidopsis* or in morphogenesis were concentrated at universities. Trying to harmonize those different types of research must have been difficult.

Yoshida: Actually, I entered RIKEN around the same time as Dr. Shinozaki. From a nearly stage I was aware that plant science research might take two directions. Dr. Shinozaki conducted plant research based on a genomic viewpoint, while I analyzed the physiological responses of plants based on their physicochemical aspects. So the idea of integrating those two through the all-Japan system was born. To a certain extent, my research depended on an appropriate combination of chemistry and plant physiology. At that time, though, this was generally not well understood. But Dr. Shinozaki's group was already conduct-

Profile

Tatsuo SUGIYAMA [left]
Special Advisor · Former Director, Plant Science Center

▶1963: Graduated from Nagoya University, Graduate School of Agricultural Sciences. Successively served as researcher, International Rice Research Institute; assistant, Nagoya University, Institute for Biochemical Regulation; researcher, John Hopkins University, School of Medicine; associate professor, Shizuoka University, Faculty of Agriculture; associate professor and professor, Nagoya University, School of Agricultural Sciences. 2001: Retired as professor from Nagoya University, Graduate School of Bioagricultural Sciences. 2000-05: Director, RIKEN Plant Science Center. Currently: Special Advisor to Center. Doctor of Agricultural Science. Specialization: molecular physiology of photosynthesis.

Kazuo SHINOZAKI [center]
Director, Plant Science Center

▶1974: Graduated from Nagoya University, Graduate School of Science. 1977: Obtained doctorate of science, Nagoya University, Graduate School of Science. Successively served as researcher, National Institute of Genetics; associate professor, Nagoya University, Department of Biology; associate professor, Nagoya University, Center for Gene Research. 1989: Took office as Chief Scientist, RIKEN Plant Molecular Biology Laboratory, and as Project Director, RIKEN Genome Sciences Center. 2005: Took office as Director, RIKEN Plant Science Center, and 2010: as Director, Biomass Engineering Program.

Shigeo YOSHIDA [right]
Coordinator, Plant Science Center

▶1971: Withdrew from doctoral program, the University of Tokyo, Graduate School of Agricultural Sciences; became research associate in the University of Tokyo, Faculty of Agriculture. 1974: Obtained Doctor of Agriculture degree. 1979: Research fellow, Australian National University, Faculty of Science, Department of Chemistry. 1987: Senior Scientist, RIKEN Chemical Regulation of Biomechanisms Laboratory. 1990: Chief Scientist, RIKEN Plant Functions Laboratory. 2000: assumed additional post of Group Director, RIKEN Plant Science Center. 2005: Coordinator, Plant Science Center, and Specially Appointed Professor, Osaka University, Graduate School of Engineering. 2011: Took office as Director, Yokohama City University, Kihara Institute for Biological Research. Specializations: plant molecular physiology and plant biochemistry.

ing research as part of the Genomic Sciences Research Center (GSC), so I hoped that we could link up with him there in order to create a new type of research center for plant science at RIKEN.

Shinozaki: Ultimately, we were fortunately able to join together and exchange information in Yokohama. We had a strong foundation in terms of personnel, and I think that's what led to today's progress.

Sugiyama: I wanted us to make maximal use of RIKEN's advantage of excelling in chemistry. The infrastructure common to the plant function research groups of Dr. Yoshida and Dr. Yuji Kamiya, and to the microorganism control research group of Dr. Isamu Yamaguchi, is a primary asset of RIKEN's plant science research. From universities, there were Dr. Kiyotaka Okada's group, researching genetic functions, and Dr. Hiroo Fukuda; they dealt with morphogenesis. Then there was the metabolic function research group of Dr.

Kazuo SHINOZAKI
Director, Plant Science Center

Tomoyuki Yamaya, which conducted function analysis, which forms the basis of today's research linked to productivity. With such a talented array of people, I believed we could create a globally preeminent research institute under any circumstances. RIKEN's president also gave me a mandate, which I agreed with wholeheartedly, and I continued to carry it out.

The Plant Science Center's Strengths, Born from Joint Research

Yoshida: Unlike a university, we had to strongly "pitch" our research results to obtain a budget, which was also somewhat perplexing to the researchers. If you don't envision a clear scenario and make a pitch that's easy to understand, public institutions will change when unforeseeable factors come along.

Sugiyama: As the center director it took me, too, quite of bit of time to achieve the necessary revolution of consciousness. In order to increase joint research at PSC, I always tried to stir up curiosity by asking people to ask themselves, "What is the person next to you doing?" Since there was an all-Japan system, I also tried my best to promote joint research through a give and take with other institutions. Internationally, too, we held two-country symposia with plant science researchers from France and from Germany. I did many things to which I was unaccustomed (laughs).

Yoshida: Joint research is important, isn't it? Actually, nearly 10% of my dissertation was a joint paper with Dr. Shinozaki. There are many cases where our methods are completely different although we're dealing with the same phenomenon, but from different angles.

Shinozaki: There is indeed the impression that university researchers and RIKEN researchers have worked well together. In particular, in Yokohama, Genomic Sciences Center of RIKEN was conducting major activities, for which it had a sizable budget, and I think it was able to make progress in part because of that budget. Also, young researchers were entering the organization, which helped in achieving various research results.

Sugiyama: One result was research that combined chemistry and physiology – research on plant hormones, which became the foundation for today's metabolome research. In this field are Dr. Yoshida's brassinosteroid, and the abscisic acid and gibberellin of Dr. Yuji Kamiya's group, right? And the cytokinin of Dr. Hitoshi Sakakibara's group. Based on these three, PSC is leading the world in plant hormone research, I think.

Also, epoch-making results were produced by the research of Dr. Hiroo Fukuda's group on morphogenesis, and by the research of Dr. Kiyotaka Okada's group

Tatsuo SUGIYAMA
Special Advisor, Former Director, Plan Science Center

on the molecular mechanisms of morphogenesis. Also noteworthy is the research on vessel formation by Dr. Fukuda's group. Then there was the progress made by Dr. Isamu Yamaguchi's group in the technical development that used plant and microbe functions related to environmental hormones and which is close to social outcomes.

Regarding such research, the Millennium Project's outside evaluating committee said, "You have obtained results that, although unspectacular, have been sound." On the other hand, from an overseas advisory council composed of experts, we received a far more glowing evaluation: "You have skillfully combined biochemistry, chemistry and molecular genetics, and grown to be one of the world's preeminent plant research institutions."

So as not to end those efforts in the first period but rather to link them to the succeeding period, we established a "Next-Period Planning Committee" in the Center; and it decided that what would be most appropriate would be to integrate the results from biochemistry, physiology, and molecular genetics and link them to what today is called metabolome research.

Shinozaki: In the next phase, under what was called the "Green Techno Plan," we sought to provide the government with various proposals through the all-Japan system. Heading into the second period was a time when new difficulties arose, wasn't it?

Sugiyama: I talked about wanting young people to develop research plans where they would play the central role and which they would be responsible for in the future. Sometimes, despite my age, I even raised my voice, didn't I? As a result of those discussions, we ended up settling on metabolomics. Metabolomics is connected to the diversity of plants. Plants have far more species than animals. Two hundred thousand doesn't even come close to the number. Diversity could be called one of the attributes of plants. Also, historically speaking, plants have been traditionally used, especially in the Orient, as so-called "medicinal herbs," for maintaining health and curing illness. From the standpoint of contributing to society, too, we ended up wanting to put our main effort into metabolomics.

Shinozaki: In that regard, in the second

Shigeo YOSHIDA
Coordinator, Plant Science Center

period, based on the Green Techno Plan, we created a plan to explore, with plant models, various genes and metabolic products that could both quantitatively and qualitatively improve plant productivity, and to then actually apply the findings to crops. One major need for achieving this was to acquire a mass spectrograph and NMR and create a new infrastructure for metabolome analysis. Another was to integrate genome, transcriptome and proteome. Dr. Yoshida contributed to create a gene expression database named AtGenExpress by international collaboration. Research to integrate that with plant hormone functions and the functions of metabolic products has progressed considerably, I think.

Towards Establishing the RIKEN Brand

Shinozaki: In the second phase of PSC, I asked Dr. Yoshida to create a system for cooperating with industry and reliably obtaining patents.

Yoshida: This project was positioned as basic research for supporting Japan's industries through intellectual properties, so we had to make its flow of operations clearly understandable. But basic researchers dealing with the model plant *Arabidopsis* prefer curiosity driven studies rather than research intended for practical applications.

So I asked them to explain the content of their research to a patent attorney, and I advised him to write a scenario with a detailed flow of operations for how to request a substantive examination of an intellectual property. This flow of operations enabled the number of requests to be greatly increased. We discovered that it is extremely important to give young people a clear map to follow. In addition, we established a new model for the projects that are sponsored by companies, in which the corporations bear the cost of the research activities, including the salaries of the researchers.

Shinozaki: With regard to requests for a substantive examination, there were about seven IP requests a year during the first period, but that number increased to twenty in the second period. I felt like there was a revolution in consciousness. Regarding our cooperation with industry, there is a corporate group called the "RIKEN Friends in Industry," and we also occasionally have Dr. Yoshida hold a networking event called "Green Innovation Plaza" (GrIP), and these led to several licensings. Two other things to which we paid attention were internationalization and hiring female leaders. At present we have three female leaders and two foreigners, so I feel that the policies which we have consciously pursued have borne fruit.

Sugiyama: In the first period we had zero female leaders.

Shinozaki: Yes, that's right. We struggled quite a bit, but in the end we were able to hire some good young leaders. Then, in the second period, many PSC team leaders were appointed as university professors. Our young leaders developed, and I feel that the individuals will form the core of plant sciences in Japan.

Also, and this is something that surprised me, but, according to Thomson Reuters, papers published by RIKEN are cited at an extremely high rate. RIKEN ranks second in the world, for the number of citations per paper, among universities and research institutions related to the plant sciences that have published at least 500 papers in the past 10 years. Number one is the world famous John Innes Center, of Great Britain. Number three is the Max Planck Institute, of Germany. We thus called this to the attention of the Independent Administrative Institution Evaluation Committee and the Advisory Council for the international evaluation. From that ranking I strongly felt that we had gained in ability and become truly international.

Sugiyama: Even domestically, many of our researchers have received the Young Investigator Award, which is given by the Japanese Society of Plant Physiologists and which might be called a gateway to success. There's that and the newly created Japan Society for the Promotion of Science Prize. Then there's the Kihara Memorial Foundation Special Award, of Yokohama – this, too, we've received for outstanding achievements.

Shinozaki: Yes, Dr. Hitoshi Sakakibara and Dr. Ken Shirasu both received it.

Yoshida: In the plant science field, Dr. Shinozaki has continued to have the highest number of paper citations for five years, and numerous other RIKEN- and PSC-related people also rank high on that list.

Shinozaki: The number of citations per manuscript of plant science ranks in the second place among all fields at RIKEN. In that sense I think plant science becomes a distinctive RIKEN brand in the world.

An Output System Geared to Industry

Shinozaki: I feel that what RIKEN has done at the Plant Science Center in the past 10 years has great importance in the

sense that, through fulfilling the role of a so-called "Research Infrastructure," RIKEN has enabled plant sciences to gain greater visibility, not only internationally but also among academic fields in general. As part of that, how RIKEN'S research differs from that of universities is now being sharply questioned.

Yoshida: Recently, at universities, the old system of class courses has been waning, and organized research has become extremely difficult to do. On the other hand, the research at RIKEN's centers functions through the organization, so, if you can effectively use that, you can produce unique strengths, I feel.

Shinozaki: I also think it was a plus that, in the second period, we were able to hold international conferences, such as the International Conference on Plant Metabolomics and the International Conference on *Arabidopsis* Research. In that way, we were able to show, I think, that RIKEN has become a center of plant metabolome research and *Arabidopsis* functional genomics.

In 2009, however, together with the change of government administration, there was a critical review of our work in PSC. And the government of the Democratic Party began asking questions. What relationship does plant science have to society? What is the difference between RIKEN PSC and the National Institute of Agrobiological Sciences (NIAS) of Ministry of Agriculture, Forestry and Fisheries? We even heard some extreme opinions to the effect that the functions of the two institutions should be rearranged and merged. At the time, however, there were a lot of public comments, made on our behalf by the plant science community and people related to it, to the effect that plant science research is important and that PSC should be protected as a base of operations in plant science of Japan. And in the end we fortunately escaped with what, I think, was a minimum of damage. Actually, opinions were also voiced to the effect that the contribution of the plant sciences was necessary for the Green Innovation which the Democratic Party was then promoting. And based on the keywords "plant science research and green innovation," we received several budget allocations. One was for the Cutting-Edge Infrastructure Development Project, which was centered at RIKEN. For this project, a total budget of 2.7 billion yen was provided for upgrading and maintaining equipment. Subsequently we participated in CREST (JST Strategic Basic Research Programs), a project related to research on plant photosynthesis and biomass and aimed at contributing to the creation of a low-carbon society. There was also the Green Network of Excellence (GRENE), a project, centered around university researchers, to increase and use plant biomass. Thus, plant science researchers joined together and showed a will to contribute to green innovation, and that, I think, made a big difference.

Sugiyama: Plants are something society hardly notices. Also, because of the vertical structure of Japanese government agencies, they don't cooperate with each other. For example, with regard to the enormous and pressing problem of the food supply, why can't knowledge developed from perspectives other than that of the Ministry of Agriculture, Forestry and Fisheries also be used? That kind of thing puts a big twist, I think, in the relationship between government and science.

Yoshida: In the future I think it will be important for the Center to have a multi-perspective survey system, so that, based on technological progress, output can be skillfully and effectively allocated according to the direction of industry.

Shinozaki: Recently, using the term "biomass" or "biorefinery," projects about how to employ the biomass created by plants in industry have been getting off the ground.

Yoshida: At present, the distinction between agriculture and industry is steadily disappearing. For example, there exists technology such as plant factories and tissue culturing. That being the case, I strongly feel that we will come to see industrial raw materials, such as rubber and oil, which have heretofore not been included under the rubric of plant science, as important subjects of ours.

Shinozaki: The metabolism research is also, I think, close to social outcomes, as is the research on oil production, the research on rubber, and the research on fiber. Much attention is also being paid to secondary metabolites related to health. Health and longevity will probably also become important areas of research and development for us. So will sustainable food production geared to climate change. Contributing to that will be an important mission of ours. RIKEN has certain problems – we don't have farm fields or greenhouses – so I think it's good that we're conducting research in cooperation with domestic and foreign researchers who have access to such facilities.

Sugiyama: Indeed, this is not an age, I think, when you can solve problems related plants with plant researchers alone or if you just research plants. But I also think that the actual power that individual living organisms have in the natural world is now finally beginning to be understood.

Our Mission for the Future

Shinozaki: I'd like to shift the focus of the conversation to how PSC should develop in the future. At present, two centers related to green innovation are planned at RIKEN. One is the Emergent Materials Science Center, which is centered around Professor Yoshinori Tokura, who came to RIKEN from the University of Tokyo; the other is the Center for Sustainable Resource Science, which is centered around PSC and will conduct basic research and development by integrating chemical biology and chemistry as well as research activities in several fields related to the creation of resources for Green Innovation. This is truly a fusion of interdisciplinary fields. An output that will contribute to society is also being demanded of us. I think it will be quite a difficult challenge, but I look forward to working hard as we approach this new phase.

Yoshida: The sensibilities of pharmacology and materials science are very close to each other, so if we can quickly find objectives that can be pursued jointly from both angles, I think we can achieve results in a very short time.

Shinozaki: As for which direction to take, one would be research on the recycling and reuse of carbon. We could improve the functions of the plant metabolic products produced by photosynthesis; we could also include chemical biology and synthetic chemistry in that effort. Also, how about if we worked on what many plant researchers have suggested, low-input crop production? In that we could also include the nitrogen problem, the absorption of phosphorous, increasing the efficiency of water use, disease resistance, and other issues. A third direction would be the recycling and reuse of metal elements. Here, I think, plants could make a big contribution: they could be used to recover rare metals and maintain water quality.

Yoshida: People from the microbial sciences will also be participating. The interaction between plants and microbes is a research field that goes back a long way. I think it's an area in which joint research will proceed smoothly.

Shinozaki: In 2010, RIKEN started a new program, the Research Cluster for Innovation. This program arose from President Ryoji Noyori's strong desire that RIKEN's research not be merely for its own sake, but rather that it promote the development of "social wisdom." In the plant sciences we have also been able to make a significant contribution to this endeavor. The Biomass Engineering Program, whose purpose is to serve as a bridge to companies who will create new biomass from chemical engineering, especially from plant materials, has been progressing through the cooperative efforts of Yokohama and Wako. This program will move in tandem with the new Center, so I expect that various plans aimed at practical application of the plant sciences will be created.

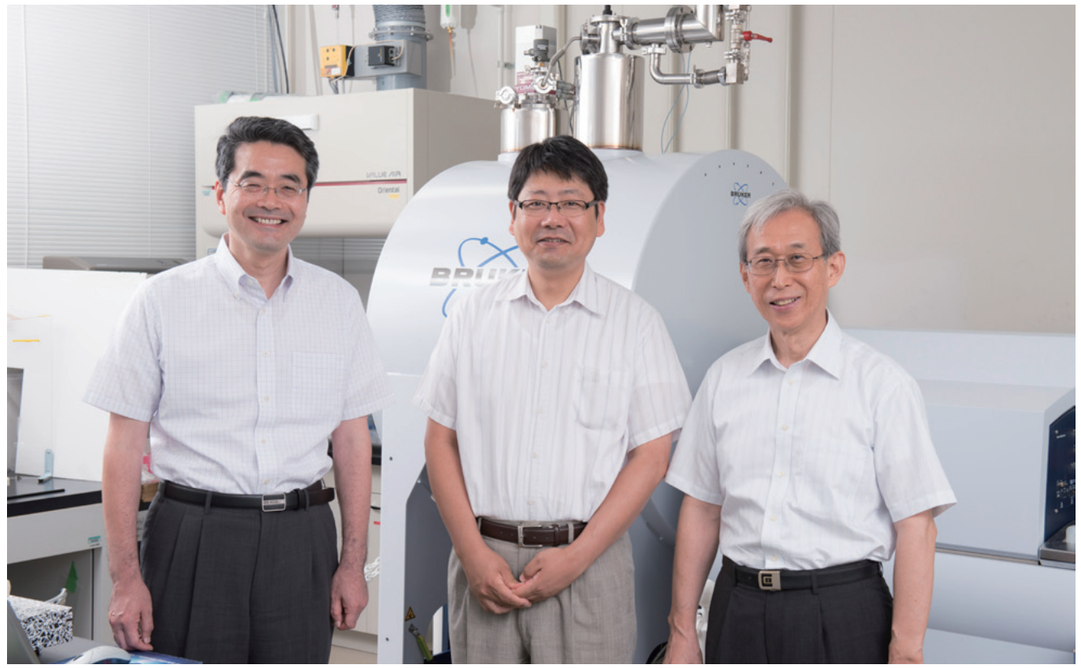
Yoshida: In a certain sense, I think the viability of the term "plant science" has ended. Initially, when we decided on the name "Plant Science Center," I was asked, "Is such a simple name good?" (laughs). However, in these thirteen years, plant science has become a science in the true sense, and since it will progressively disappear into a larger science, I think that our name has finished serving its purpose.

Sugiyama: I agree.

Shinozaki: What's most difficult is collaboration with industry. In the future we'll probably be doing applied research on such subjects as, How do you use plants not just as food but also as industrial material? Or: How do you find things that will contribute to health? In any case, collaboration, including international collaboration, will become vital for us in the future, I believe.

Fusion between Genomics and Metabolomics

The Plant Science Center (PSC) inherited the direction of research set by the Plant Functional Geniomics Research at Genomic Sciences Center (GSC) and strong biochemistry and hormone research in the fist period of PSC, and in 2005 embarked on a new metabolomics-based genome research. Three scientists who have successfully promoted interdisciplinary research under the watchword of "collaboration" speak about the strengths of PSC in functional genomics and the future steps towards building connections between plants and the industry.



Reasons for the Focus on *Arabidopsis*

Shinozaki: In the last 20 years, "genome" has been the keyword in the development of plant science. RIKEN, and particularly the Yokohama Institute, promoted genome research with the Plant Science Center (PSC) playing a role from a new perspective of metabolomics. In this process, the sequencing and analyses of *Arabidopsis thaliana* and rice genomes were key developments. Whereas countries had their own resources of cultivated rice species, *Arabidopsis*, for which there were no practical commercial uses, was freely used for research from the outset. This, I think, led to promoting international collaboration.

Saito: I agree. Another important development I would point out would be the establishment, immediately preceding the sequencing of the genomes, of in-planta transformation technology (introduction of genes) for *Arabidopsis* and transformation technology for rice using Agrobacteria.

Shinozaki: Such technology development was followed by sequencing of the entire *Arabidopsis* genome in 2000, a release of a draft sequence of rice genome in 2001, and sequencing of the entire rice genome in 2004. But even before that, we saw some characteristic advances in individual genome research projects, didn't we? For example, RIKEN Genomic Sciences Center (GSC) initiated human genome analysis, collection of full-length complementary DNAs of mouse, and structural analysis of proteins in its core projects, which precipitated "saturation mutagenesis" that tries to analyze biological functions by gathering a large number of mutants. This, in turn, led to the birth of PSC. As for preparing resources such as mutants and full-length cDNAs, it began in the GSC days in the form of Japan contributing to an international network, didn't it?

Matsui: To analyze individual gene functions, it is simply essential that you have access to mutants as research resources. RIKEN promoted collection of full-length cDNAs and mutants, which included plans for international collaborations. There are two types of mutants. One group is the transposon-tagged mutant line, which destroys genes, and the other is the activation-tagged mutant line, which activates genes. We used these resources to analyze gene functions based on reverse genetic approaches.

The Dawn of Metabolomics Research and Development of PSC

Shinozaki: In 2005, PSC launched new metabolomics-based genome research with Dr. Saito joining forces. Were there any reasons that the uptake of metabolomics started mainly from the plant sciences?

Saito: We use plants as foods and raw materials for drugs and industrial energy, all of which are dependent on their inherent metabolic functions. Therefore, we realized that it was important to study metabolism that contributed to plant utility. Another reason, I think, is the remarkable chemical diversity of the plant metabolome. If humans have 3,000 to 5,000 metabolites, plants have over 200,000 metabolites, mostly called as 'secondary metabolites'. Some recent estimates say 1 million. When we started the research, full-length cDNAs, mutants, and other resources were becoming available, so there was a sense that the time was ripe. In other words, it coincided with the beginning of integrated omics research that tried to have one-to-one matches between genome functions and metabolites. Because this kind of omics research could not be conducted by university laboratories, we were acutely aware when we started that we had a role in providing a kind of a platform that would "contribute to the entire plant science community."Our metabolome research was a project for building a research platform by fully utilizing some of the unique features of RIKEN.

Shinozaki: I have a real sense that PSC is gradually becoming well-known globally today. I suppose that having outstanding, leading scientists come to work at the Center was a major factor.

Saito: One characteristic of RIKEN and of PSC, for that matter, is that each scientist is high-minded about his or her research and is committed to leading the wider science community. I think that is an integral part of the respect that RIKEN has come to earn around the world.

Matsui: It would be hard to find a center with such a convergence of experts from different fields. Regular meetings and research presentations allow us to know what each of us is doing. We conduct joint research freely, which generates new ideas. We use new equipment to conduct some truly unique research.

Shinozaki: Speaking of new equipment, the development of metabolomics research came in tandem with the development of mass spectrometry, I believe.

Saito: True. We were fortunate to have a full lineup of mass spectrometers, including time-of-flight mass spectrometry (TOF-MS), Fourier-transform mass spectrometry (FT-MS), and even triple quadrupole mass spectrometry. Also notable is that we have an NMR center in the Yokohama Institute. Ours is probably the only center in the world with a full lineup of mass spectrometers and NMR all on a same platform.

Interdisciplinary Metabolomics Research

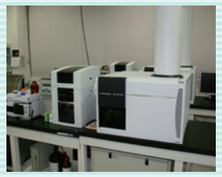
Shinozaki: While collaboration is one of the strengths of our Center, I feel that metabolomics scientists are particularly good at forming collaborative networks. You collaborated with Professor Masaru Tomita of Keio University at Tsuruoka Campus in introducing capillary electrophoresis mass spectrometry, and you shared a database called Mass Bank internationally, just to give a few examples. Does this mean that cooperation was necessary to promote research as a whole?

Saito: One of the reasons is that we are naturally not as aggressive as scientists in

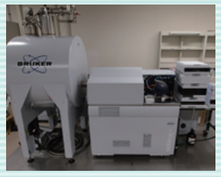
❖——Mass spectrometers at PSC

▶GC(xGC)-TOF-MS

▶UPLC-Q-TOF-MS



▶CE-TOF-MS



▶LC-FT-ICR-MS

▶UPLC-TriQ-MS

▶700MHz NMR

Profile

Kazuki SAITO [left]
Deputy Director, Plant Science Center

▶1977: Graduated from the University of Tokyo (Faculty of Pharmaceutical Sciences).1982: Obtained Ph.D. in pharmaceutical sciences. After staying at Keio University, School of Medicine and Ghent University in Belgium, he was appointed as a professor at Chiba University, Graduate School of Pharmaceutical Sciences in 1995. 2005: Group Director at RIKEN Plant Science Center. 2010: Deputy Director of RIKEN Plant Science Center. He was awarded the Commendation for Science and Technology (research division) by the Japanese Minister of Education, Culture, Sports, Science and Technology in 2010 and the JSPCMB Award for Distinguished Research in 2011. He specializes in metabolomics-based functional genomics, biosynthesis of plant metabolites, and biotechnology.

Minami MATSUI [center]
Group Director,
Plant Functional Genomics Research Group

▶1981: Graduated from Saitama University (Department of Biochemistry and Molecular Biology, Faculty of Science). 1986: Obtained a degree of Doctor of Science from Kyoto University, Graduate School. 1992: Studied at Yale University. After returning to Japan, he was appointed as Deputy Head of RIKEN Frontier Research Program's Laboratory for Photoperception and Signal Transduction in 1995. 1999: Appointed as Team Leader of RIKEN Genomics Sciences Center, Plant Functional Genomic Research Group. 2006: Appointed to the current post. He is involved in the development of the *Arabidopsis* activation-tagged line and gene exploration methods using full-length cDNAs of *Arabidopsis* and rice.

Kazuo SHINOZAKI [right]
Diretor, Plant Sciense Center

▶P.011 Reference.

Kazuo SHINOZAKI
Director, Plant Science Center

other basic biology or genome research (laughs). In some respects, we cannot carry on our research without cooperation. Another thing is that the size of the community is just about right for forging collaborations among scientists. For example, a new project that came out of that is a joint effort between the National Science Foundation (NSF) and Japan Science and Technology Agency (JST) for research on "Metabolomics for a Low-Carbon Society." This is a good example where forging and maintaining an array of collaborative relationships has led to a framework for a joint public research project between Japan and the United States.

Shinozaki: It seems to me that there is, relatively speaking, quite a lot of cooperation within the plant science community. Even when competitive relations develop, they seem to manage quite well by sharing. This approach is actually like plants' in that you occupy segregated habitats but combine your respective outputs (laughs).

Saito: On the other hand, we might produce toxins if we are overstressed (laughs).

Results of Metabolomics Research

Saito: We have had several results from our metabolomics research, one of which is research on assigning genome functions of rice that was undertaken with Dr. Matsui's group. More recently, we published a paper on metabolomic QTL of rice. Another is research using *Arabidopsis*. In this research, we were able to determine new gene functions using the AtMetExpress database and by combining metabolomic approaches, to identify important genes associated with such secondary metabolites of plants as glucosinolates and flavonoids. In terms of applied research, we were able to propose a method for evaluating the substantial equivalence of genetically modified plants. We also had results with medicinal plants. For example, I think our research to determine genes involved in the production of glycyrrhizin in licorice roots and biotechnologically produce glycyrrhizin is a new type of research that derived from metabolomics.

Shinozaki: My group also had results coming out of joint research with Dr. Saito on environmental stress.The methodology of focusing not only on gene expressions but also exhaustively comparing them with metabolites was extremely effective. We were able to discover new metabolites that protected cells affected by stress. By conducting gene expression analysis simultaneously, we were also able to identify important transcription factors that regulated genes. We believe that we can make many new discoveries using this analytical system.

Launch of Plant Transformation Network (TRANSNET)

Shinozaki: In seeking ways to apply basic research in actual crops, we launched the Plant Transformation Network (TRANSNET) with Dr. Matsui's group in 2008. This, I think, set a direction of the Center in some respects.

Matsui: In the TRANSNET that the Center is supporting, we ask transformation experts to incorporate useful genes taken from *Arabidopsis* or other plants into practical plants, so we can verify their transformations. The crops that we actually use are tomatoes, soybeans, and rapeseeds, and we asked the assistance of Professor Hiroshi Ezura of University of Tsukuba, Dr. Masao Ishimoto of NARO Hokkaido Agricultural Research Center, and Professor Jun Imamura of Tamagawa University, respectively. Once the TRANSNET became operational, we received quite a large number of requests, and we are currently moving ahead with the analysis.

Shinozaki: With regard to transformation, in 2003 Dr. Matsui and his colleagues launched the venture company Inplanta Innovations Inc. to offer RIKEN's technology and infrastructure.

Matsui: It is the first plant-based venture company to come out of the Yokohama Institute and is founded on three key components: a system for comprehensively adding specific functions to plants, gene mapping, and transformation. The company is conducting joint research on the development of transformations in a range of useful plants.

Future Developments in the Employment of Useful Plants

Shinozaki: I would now like to turn to the subject of future developments. How do you see the future in terms of metabolomics platform?

Saito: One thing that is clear is that genome research, which has been limited to a number of what are known as model plants, will expand to all of the 200,000 plant species. From the perspective of how we integrate transcriptome and proteome, I also think that omics research focusing on the usefulness of plants will be essential. For example, there could be

Kazuki SAITO
Deputy Director, Plant Science Center

Minami MATSUI
Group Director, Plant Functional Genomics Research Group

extensive research on the mechanisms of how substances, such as lipids and carbohydrates, which are sources of energy, are produced in plants that produce energy. In medicinal plants, there could be research on how specific metabolites are produced. Ultimately, we need to go beyond basic research and expand into fields that are more closely related to our daily lives, such as industry, bioenergy materials, drugs, healthful food components, and increasing food production, which also tie in with the Japanese government's Green Innovation and Life Innovation policy goals.

Shinozaki: I agree. In contrast to genome research, which so far has been like writing an encyclopedia, I have the impression that we are now at a point where we can write textbooks, so to speak, on individual biological systems. Therefore, I expect there will be research done to link the ways individual genes relate to each other and guide them to specific functions. The other is the application of synthetic biology. I feel we are probably entering a new era where humans will work on living beings to generate new added value. In this respect, we note that PSC launched RIKEN Biomass Engineering Program (BMEP) in 2010.

Matsui: I think synthetic biology will become important in the span of the next five years. Some of the central issues may be how we use the genetic information we obtain from decoding genome sequences of a variety of living beings to introduce new pathways within plants and thereby efficiently produce useful metabolites or introduce new metabolic pathways or synthetic pathways for producing such materials as biomass or bioplastic.

Future Roles of Plant Science

Shinozaki: RIKEN is now promoting organizational integration and restructuring, and will establish a new center that will be related to the environment, energy and resources. In this context, we are having discussions about the role of PSC in conducting research that would contribute to the government's Green Innovation policy objectives in conjunction with chemical biology, synthetic chemistry, and catalytic chemistry. This is a challenge that aims to improve food production as well as to create sustainable, environmentally friendly production systems based on organisms like plants and microbes. I think you will both agree that plant science will play a very important role in this.

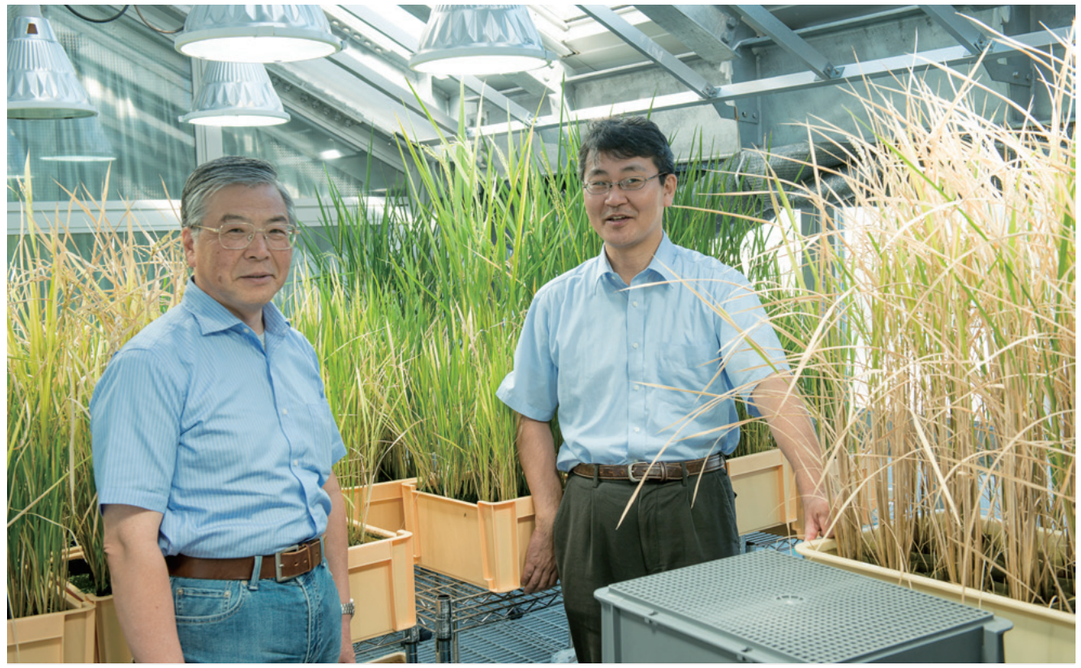
Saito: In terms of fusion with chemical biology and catalytic chemistry, I think a photosynthesis platform, where carbon dioxide assimilation occurs and where ultimately plants are provided high value added also through the help of microorganisms, would be an important keyword to further expand on the achievements of PSC. This system will not be limited to metabolomics research in the narrow sense, but will also relate to everything from stress biology to developmental biology and hormone and metabolic regulation. In terms of output, synthetic biology will also be included.

Matsui: In my mind, the linkage between chemistry and plants and microorganisms is inevitable. In a county like Japan with a heavy emphasis on manufacturing, research that joins photosynthesis of plants with materials production should be interesting. I think that the RIKEN Biomass Engineering Program (BMEP), when it is integrated into the new center, can also play a role in providing connections between plants and the industry.

Shinozaki: One of the expressions that RIKEN President Ryoji Noyori likes to use is "WEHAB + P"(Water, Energy, Health, Agriculture, Biodiversity and Poverty), an acronym summarized by Kofi Annan, the seventh U.N. Secretary General, to describe the most pressing issues facing humanity. The new center named Center for Sustainable Resource Science, no doubt, will be promoting basic research in pursuit of providing some of the solutions to these important issues.

Plant Hormone Research at the Plant Science Center

The trend of plant hormone research in Japan was passed on to the Plant Science Center, becoming one of the cores of the Center. In the face of the pressure of rigorous external assessments, the Center steadily turned out research contributing to improvement of crop productivity. Two scientists exploring plant hormones from the perspectives of chemical genetics, biochemistry, and molecular biology talked about the results of plant hormone research and their enthusiasm for future research.



A Prehistory of Plant Hormone Research and Use of Mass Spectrometry

Kamiya: A history of plant hormone research provided a background for the establishment of the Plant Science Center (PSC). Soon after the war, Dr. Yusuke Sumiki, the former vice president of RIKEN, elucidated the chemical structure of the toxin produced by *Gibberella fujikuroi*. This research was an important work of this early period. Partly because Dr. Sumiki was enthusiastic about gibberellin, a progress was made in gibberellin research in Japan.

It was Dr. Akira Kawarada, who was the chief scientist of RIKEN's plant pharmacology laboratory, first discovered in Japan that gibberellin was an endogenous hormone of plants. He took water sprouts from *Citrus unshiu* (Japanese mikan) tree to look for growth promoting substances causing the elongation in rice bioassays, and discovered that it was gibberellin A_1. This time consuming research deserves greater recognition, but Jake MacMillan's paper on the research on gibberellins in immature seeds of *Phaseolus vulgaris* is more often cited.

With the appointment of Dr. Nobutaka Takahashi as a chief scientist and executive director for research at RIKEN, plant hormone research went ahead in RIKEN at around 1975. It was by his recommendation that I began research on gibberellins. At that time, we did not have any concept like genomes, but there was a sense that we could approach genes through identification of hormonal enzymes.

Sakakibara: I was initially involved in research on nitrogen nutrition in my PhD study. I knew that a plant hormone called cytokinin may be involved as a second messenger in the regulation of plant development by nitrogen nutrition. But because I was in a plant nutrition lab, I had never used the mass spectrometer before joining RIKEN (laughs). The entire genome sequence of *Arabidopsis thaliana* was published in the same year that PSC was established. I feel that the successful fusion between genetics, using *Arabidopsis*, and chemistry, using mass spectrometry, owes much to the research environment provided by RIKEN.

In the end, I think the history of my research at RIKEN overlaps with the history of the development of mass spectrometry. When I first came to RIKEN, we were using the rotary evaporator, ones that students typically use, to measure each sample by rotating the evaporator. And then it became possible to measure 12 samples at once, and the number has since increased to 192 samples. In addition, we can now measure a sample size that is a hundredth or a thousandth of what was possible in the early days. The introduction in 2003 of the high-performance liquid chromatography- tandem quadrupole mass spectrometry (LC-qMS/MS) was definitely a turning point.

Kamiya: In raising the high sensitive plant hormone analysis, there is inevitably a need to introduce MS spectrometer with high resolution. We introduced the liquid chromatography / time-of-flight / mass spectrometry (LC-TOFMS) in 2005. This MS spectrometer had high resolution, but its sensitivity was not enough for our quantification of hormones. Therefore we intorduced quadrupole LC-MS/MS. By using these two different MS spectormeters, it was possible to analyze hormones at a high level of reliability. Subsequently, I could measure the accurate endogenous levels of hormones in my papers. At any rate, when people and equipment are invested in research and provided that the research is founded on a strong concept, the quality of research papers will inevitably improve.

❖——Results of Plant Hormone Research at RIKEN Plant Science Center

Research on biosynthesis and metabolism of gibberellin, brassinosteroid, cytokinin, auxin, and abscisic acid
Identification of abscisic acid and polyamine transporters
Discovery of the new plant hormone strigolactone
Integrated research on plant hormones involved in seed germination and dormancy
Simultaneous analysis of plant hormones and related gene expressions
Analysis of plant hormones and environmental responses related to desiccation, salt stress, and nutrition
Simultaneous high-sensitivity, high-resolution analysis of endogenous levels of plant hormones using LC-MS/MS

RIKEN Spirit Conducive to Joint Research

Kamiya: Because we were strong on biochemistry, there was a feeling that we were competing in slightly different fields when compared with overseas plant laboratories. For instance, we were dealing with cytochrome P450 (a generic term for a family of enzymes that catalyze oxidation) that are involved with major plant hormones. You, for one, were trying to identify the genes involved with hydroxylation of the side chain of cytokinins, weren't you, Dr. Sakakibara?

Sakakibara: Yes, that paper was published in 2004. We used a screening method based on mass spectrometry. We were really fortunate to be working in RIKEN that had the necessary analytical technology.

Kamiya: After the launch of the PSC, we headhunted Dr. Eiji Nambara because we were interested in abscisic acid and he could promote research both on abscisic acid and gibberellin. He had two research themes. One was cloning of cytochrome P450, which is a catabolic enzyme of abscisic acid. In agriculture, this is very important. The other was the abscisic acid receptors. For nearly ten years, a Canadian group had been a leader in the functional analysis of ABA degradation cytochrome P450 using enzyme purification, but Dr. Tetsuo Kushiro took practically less than a year to catch up using a reverse genetic approach. The first device that Dr. Kushiro wanted us to purchase was the old style French press that is used to extract enzymes from microorganisms (laughs). He was probably the first person to succeed in producing enzyme activity with a device that looks like cast iron.

Sakakibara: Even if we know the genome information, we normally do not have a method to verify it. But at RIKEN, collaboration is possible with multiple research teams, and unlike in a university where there are boundaries between research groups, there is a sense within RIKEN that we can freely strike up joint research.

Kamiya: We are a "family."

Sakakibara: It's a "We are in the same boat" mentality, right? (laughs).

Kamiya: It's a blood relation linked by research. As long as we are a family, we can't lock ourselves up in our small, little rooms.

Sakakibara: The meetings for reporting research progress within the Center provided opportunities for constructive criticism before a paper was submitted and everybody knew what the paper was about by the time it was actually published. This, I think, also promoted joint research. Dr. Kamiya and I also have three or four papers that we co-authored.

Kamiya: For an institute like RIKEN that needs to have advanced technology development and international competitiveness, it is very important that we build networks around the world and bring

Profile

Yuji KAMIYA [left]
Group Director,
Growth Regulation Research Group

▶1975: Graduated from the University of Tokyo, Graduate School of Agriculture after completing the doctoral program. In the same year, he joined the Pesticide Synthesis Laboratory 3 of RIKEN as a researcher. 1980: A research fellow at University of Gottingen for two years. 1991: Served as the Team Leader of the RIKEN Frontier Research Program, Laboratory for Plant Hormone Function for eight years. 2000: Served as Group Director of the Plant Science Center, Growth Physiology Research Group for five years. 2005: Appointed as Group Director of the Growth Regulation Research Group.

Hitoshi SAKAKIBARA [center]
Group Director,
Plant Productivity Systems Research Group

▶1988: Graduated from Nagoya University (School of Agricultural Sciences). 1992: Withdrew from the doctoral program at Nagoya University, Graduate School of Bioagricultural Sciences. In the same year, he was appointed as a Research Associate at Nagoya University. 1995: Obtained Ph.D. in agriculture. 2000: Joined the RIKEN Plant Science Center as Team Leader of the Communication Mechanisms Research Team. 2005: Team Leader of the Biodynamics Research Team. 2006: Appointed as Group Director of Plant Productivity Systems Research Group.

Yuji KAMIYA
Group Director,
Growth Regulation Research Group

down barriers among scientists and help each other out. And this is also one of the merits of RIKEN's basic research.

Sakakibara: Because PSC started out as a time-limited project, we were subject to rigorous inspection every two or three years and there was a lot of pressure. In those circumstances, I was able to identify three key genes involved in the biosynthesis of cytokinin from 2001 to early 2007, and I think it was good that I was able to gain global recognition for cytokinin biosynthesis.

Building a Brand for the RIKEN Plant Science Center

Kamiya: I think it was around 2006 that Dr. Shinjiro Yamaguchi began his research on strigolactone. It was a happy amalgamation of Dr. Yamaguchi's excellence in biochemistry and Dr. Mikihisa Umehara's plant cultivation technique that led to the big discovery in a short period of time. Our hunch was that strigolactones did not exist for the parasitic plant *Striga*, but were actually plant hormones.

Sakakibara: The results were published in Nature in the same issue that a French group published their results, wasn't it?

Kamiya: Yes, a friend of mine from overseas advised me that a similar paper would be published soon, so we were getting all geared up to publish ours (laughs). But Dr. Yamaguchi was really cautious and said he wanted the paper to be perfect so that he could be sure it would be accepted. That made me really nervous, but we waited until the last minute before submitting the paper. We learned that by that time, their paper was already being examined. It was really a close call. It reminded me how important it was to have an international network.

Sakakibara: It's also about building a brand for RIKEN Plant Science Center so that the Center is recognized everywhere, isn't it?

Kamiya: During the time I was an international advisor for the Annual Review of Plant Biology for ten years starting in 2000, I had a small wish of having many principal investigators (PIs) at PSC contribute articles for the journal, because that would increase the number of citations from PSC. There are several research institutes in the world that call themselves plant science centers. Among them, RIKEN's has its strength in hormone-related biochemistry. After Dr. Kazuki Saito joined our Center, we have added a new strength in the field of metabolomics.

I am actually hesitant about entering other fields where somebody else is already working on. For example, in gibberellin research, my area of specialization is mainly biosynthesis. Professor Taiping Sun is in the field of signaling, and the University of Tokyo and Professor Makoto Matsuoka are in the field of receptors. The remaining field of transporters is important but nobody is doing this research. That's why when Dr. Mitsunori Seo put his hand up to do the research, I thought it was suitable as the next generation of research, and I would very much encourage him to pursue this path. In sum, whereas we extract hormones from the entire plant and analyze them, research on transporters elucidates how hormones are transported from individual cells and how they are consumed. This is research for the future.

Sakakibara: From my experience of dealing with nitrogen and cytokinin, I knew from literature that there were antagonistic interactions with abscisic acid.

Kamiya: It is well-known that at low concentrations, abscisic acid promotes root growth. In Japan, abscisic acid is mixed in fertilizers. It is an interaction between practical agricultural applications and transporters.

Sakakibara: It was Dr. Takashi Kuromori, in Dr. Shinozaki's research group, who identified the ABC transporter. I was saying to myself, "So this is the abscisic acid transporter," when Dr. Seo used another completely different screening method and found another transporter gene that had previously been identified as a transporter for nitrate ion, and this surprised us all. From this new vantage point, we realize that there was actually substantial literature where both nitrogen nutrition and abscisic acid were involved.

Kamiya: It was the discovery of the abscisic acid receptor that led to Dr. Seo's ideas. Receptors do not recognize hormones on their own but form complexes to do so, and Dr. Seo skillfully integrated this into his yeast-based screening system. An advantage of this screening method is that it can be used for other plant hormones. Now that his research has been published, I would think other scientists will start using this system.

Hitoshi SAKAKIBARA
Group Director, Plant Productivity Systems Research Group

On Scientist with a Trademark

Kamiya: When we were getting ready to organize new teams in 2005, Dr. Hiroyuki Kasahara, Dr. Mitsunori Seo, Dr. Shinjiro Yamaguchi and I stayed overnight to discuss the future of our research. One of the things I talked about was the importance of each scientist, and particularly

young scientists, to have their own trademarks. Scientists should not be swayed by the trend. It is important we carry our own banners. As for me, I decided on a theme and have always pursued it. People said hormones are out of date and that I should move on, but I believe if you stick to what you believe in, something good has to come out of it. I think you should all stand firm and continue with what you really want to do. In the end, it's when you are doing what you really want to do that your research has the greatest strength.

Sakakibara: One of the reasons we were able to continue research on plant hormones at RIKEN was that we clearly demonstrated that plant hormones were closely related to productivity and plant development. When we entered the second period of PSC, there was a numerical target for raising plant productivity by 30%. In that process, we were able to demonstrate, even in our papers, that gibberellins and cytokinins are plant hormones actually involved with productivity and therefore, research on plant hormones is important for improving productivity. That was probably also one of the reasons that plant hormone research became one of the cores of research at PSC.

Kamiya: I was originally in a pesticide laboratory, so I actually did research with people from private companies. The size of the gibberellin market is very small if you look at the entire agricultural chemicals market. But even then, fine tuning with hormones is very important. It will be indispensable for aseptic culture in future plant factories.

Sakakibara: With further improvement in mass spectrometry technology, some scientists at other RIKEN centers are attempting to conduct mass spectrometry on a sample that consists of only a single cell. If we can go down that path, I think we will ultimately be able to clarify the dynamics of plant hormones in single cells. Another thing is that I think there are still many undiscovered plant hormones. In those respects, I feel there is still much room where RIKEN can contribute. The overall direction of research at the Center will probably change next year. Still, scientific excitement is a hallmark of RIKEN's research we need to preserve, and I hope to take on exciting new challenges. I also feel, without any exaggeration, that development of PSC owes much to you Dr. Kamiya, who, as a leader in plant hormone research in Japan, maintained friendly communication with all sorts of people.

Kamiya: PSC was open to the world ever since its birth. I think that's very important. When I was a student, I felt utterly humiliated when scientists overseas called Japanese scientists who had done exceptional work not by his or her name, but simply as the "Japanese scientist." For me, I will respect a scientist for the research that he or she has done. Affiliation is irrelevant. For PSC to gain in strength, how it will change is very important. I think I was able to survive because I was always willing to change. Young people need to change after being appointed to their new positions. It's important that they set their aim on new directions that few people have even thought about.

Sakakibara: I agree. I think there are still many more undiscovered treasure-troves in the world of plant hormones (laughs). The only other requirement is devotion and enthusiasm.

Internationalization of the Plant Science Center

The Plant Science Center provides a strong research environment and support system for receiving foreign researchers. Following the trend in internationalization, the Center also actively promotes joint research with overseas laboratories, which enhances the profile and brand of the Plant Science Center. A staff member of the RIKEN Global Relations Office and a scientist who has hosted a number of foreign researchers at his lab discuss the internationalization of the research environment at the Plant Science Center.

Special Postdoctoral Researchers Program Supporting the RIKEN brand

Shirasu: I took up my current position at the Plant Science Center (PSC) in April 2006, about five years after the Center was established. At that time there were very few non-Japanese researchers at either RIKEN or PSC. There were a number of reasons for this, I believe. First of all, there was very little support for foreign researchers at the time, and the seminars as a general rule were conducted in Japanese, so it was not an environment where foreigners could easily participate unless they were proficient in Japanese. I had just returned from overseas and, as a scientist, I personally found the working environment very odd and felt that making the organization more international would definitely be to our advantage.

Shimizu: I joined RIKEN in 2007 as the person in charge of the newly established Foreign Postdoctoral Researcher (FPR) program, the equivalent of the Special Postdoctoral Researcher Program but for overseas researchers. At that time the initial recruitment was already underway in preparation for the first intake of foreign researchers in 2008. The labs select their applicants in advance, so I believe there is a high level of competition in the placement of these overseas researchers.

Shimizu: PSC has hosted six Foreign Postdoctoral Researchers to date. Two of the six came to my lab. Both were very competent female researchers from Australia. This year we will see an increase in the number of FPRs, and I believe in the end we will host about eight at a time. About 30 foreign researchers also come to PSC under the Postdoctoral Fellowships for Foreign Researchers program sponsored by the Japan Society for the Promotion of Science (JSPS). Their stay is for a maximum of two years, however. Unlike for FPRs, there are no positions under this program that allow for a three-year stay. Therefore, I feel those who come on the FPR program have a greater opportunity to engage in research as core researchers here at PSC.

Shimizu: This must be a very meaningful program in terms of activities at your laboratory.

Shirasu: It certainly is. The compensation package provided for the researchers is also very generous. It is definitely a special scholarship program even by international standards, and it has turned out some very outstanding people. I feel FPR is achieving success as a prestigious program that will contribute significantly to making RIKEN an international brand.

When it comes to internationalization, the importance of critical mass is always foremost in my mind and the ratio of overseas researchers I always bear in mind as a target is 30%. In other words, I consider having three out of 10 researchers from overseas as a reasonable ratio. At our lab, however, this ratio has at times reached as high as 50%.

If we have a number of overseas researchers in the program, they can share their knowledge about living in Japan with each other. But unless we develop a welcoming research environment, researchers will not come here, and unless they come, we cannot continue this program. What we have to do is to create an attractive environment that will entice talented researchers to join our program, so we can continue to host researchers from various countries. It is always my hope that our overseas researchers will return to their countries with good impressions of the PSC that will lead to the next recruitment of overseas researchers. Their first impression will be based on whether or not systems and procedures are in place in the research laboratories. In some cases, we have had researchers with us for only a three-month period but who later applied for the FPR or JSPS program. Therefore, we perhaps need to treat short-term researchers with particular care as potential PR messengers for research at PSC.

Shimizu: I also think the arrangements for our foreign researchers are very important. If they speak enthusiastically about the kind of research they were able to engage in and the kind of research environment they experienced here when they go back to their home countries, people will have a positive image of RIKEN. Therefore, I think it is important to turn foreign researchers that come to Japan into avid fans of RIKEN.

Giving Priority to English at the Plant Science Center

Shirasu: One thing that overseas researchers find quite offputting when they first enter the research lab is the amount of notices and signs written in Japanese. Even though they can imagine that these notices contain important information, they have no idea what they say. If we think about it, that kind of environment is actually very exclusionist. To remedy this, we decided to give English priority over all other languages in my lab and not to allow any sign or notice unless it was also in English. I also asked other sections with whom we share the work environment to cooperate in this initiative. Of course, there are some who complain that this arrangement is rather troublesome, so it is still a bit of an uphill battle.

Shimizu: It must be quite a challenge. As we know, Japanese are generally quite proficient at reading English but quite hesitant when it comes to writing.

Shirasu: The same goes for email. First of all, I have told everyone at the lab that I want all email in English. When they are composing email, I ask everyone to write in English first and then in Japanese. The reason for doing this is because I find that when researchers who cannot read Japanese see a message written in Japanese first, they tend to dismiss the entire message. The decision to make English the official language at seminars within PSC took about a year to make but today I am glad that I pushed for this.

Shimizu: I think that is great, because it is important for Japanese to acquire a foreign language. At the same time, I feel it is important for children to be able to study science in Japanese during their primary education. Whether it is physics or biology, I have heard that there are not many countries where people can study such subjects in their mother tongue alone.

Shirasu: I believe there are various views on the subject but being able to think in one's mother tongue is an extremely strong argument.

Shimizu: If Japanese were proficient at their own language as well as a foreign language, I believe they would be in the most advantageous position in scientific research too. Just the other day I was reading a book by science journalist Shimpei Miyata, with a title that in English means: "A Paradise of Freedom for Scientists – The Glory of RIKEN". It seems that researchers in the Meiji Period were not inclined to differentiate between the arts and sciences. When I read the part describing how Dr. Kikunae Ikeda, who was instrumental in the founding of RIKEN, had a strong influence on the writer Soseki Natsume, I felt that it would be great if scientists today were knowledgeable in the arts as well as sciences.

Shirasu: To be both a person of letters as well as a scientist, I feel, is quite appropriate. In today's world, however, we deal with a massive amount of information, and people in science without competency in English will be at a decided disadvantage in their fields. However, I think it would be good to have scientists who not only can speak English well but also have a sound understanding of Japanese literature and can express it in English. At any rate, I think we agree that it is very important to create an environment where people are proficient in both English and Japanese.

Creating a Support System and Community for Overseas Researchers

Shimizu: Although English is understood at our institute, foreigners who can't speak Japanese generally have great difficulty in conducting their everyday affairs

Profile

Yunike SHIMIZU [left]
Program Coordinator for Junior Scientists, Global Relations Office, RIKEN

▶Research Personnel Support Section, Global Relations Office, RIKEN
2007: Joined RIKEN. In charge of Foreign Postdoctoral Researcher Program at Research General Affairs Section, DRI/FRS Promotion Division. Since 2010: In charge of programs for junior scientists at Research Personnel Support Section, Global Relations Office.

Ken SHIRASU [right]
Group Director, Plant Immunity Research Group

▶1988: Graduated from the University of Tokyo, Faculty of Agriculture, Department of Agricultural Chemistry. 1993: Awarded Ph.D. in genetics at University of California, Davis. After studying at the Salk Institute for Biological Studies (United States) and the Sainsbury Laboratory (Great Britain), became an independent PI at the Sainsbury Laboratory. 2005: became Group Director at RIKEN Plant Science Center. Since 2008: visiting professor at the University of Tokyo Graduate School.

Ken SHIRASU
Group Director,
Plant Immunity Research Group

in Japan and often comment that they don't know where to begin.

Shirasu: Yes, it seems the first one or two weeks after arrival in Japan can be quite difficult. Initially, the individual labs offered support to some extent, but PSC now has a dedicated person who was employed to look after our researchers from overseas. Procedures and systems have also been put in place to help with the kinds of difficulties that all newcomers encounter. We also provide all kinds of information to overseas researchers prior to their arrival in Japan. And the moment they arrive, we are there to give them reassurance and any support they might need. We want them to get off to a smooth start so that they will have the impression that Japan is a wonderful place to live. Once they get over the initial one to two weeks without any major issues, the people at their respective laboratories will be able to help in whatever way they can.

Shimizu: The Global Relations Office has a translation team, and many of the rules and regulations have already been translated into English. This has been very useful to non-Japanese staff. The Help-Desk at the Brain Science Institute (BSI) on the Wako Campus also serves as a model for other universities, and we have visitors from those universities coming to see how it operates.

Shirasu: Perhaps no other research institutes or universities in Japan provide as much support to foreign researchers as we do. RIKEN can serve as a template for universities that want to increase the number of their foreign researchers. I think it would be ideal for RIKEN to take the lead in internationalization in this respect. As the number of overseas researchers increases, a community of foreigners naturally forms without the assistance of Japanese staff. In Yokohama, there is a network of overseas staff, more like an international village, which is quite active outside PSC. But it takes a lot of time for this to occur. It is important for us to create opportunities for people to get together in activities outside the science environment. It can be anything – like football or other social events.

Shimizu: Once a month the Global Relations Office holds an event called "Discovery Evening" on Wako Campus. This is for researchers of the Special Postdoctoral Research and Foreign Postdoctoral Research programs as well as postgraduate students. In the future, we hope to hold similar events at the Yokohama Campus too. We would also like to plan events where both non-Japanese and Japanese alike can participate.

Disseminating Information about the PSC Brand and Research Environment

Shimizu: I have heard that in Germany scientists cannot establish a successful career path in their own country unless they do some postdoctoral study abroad.

Shirasu: That is correct. And that is why many German researchers go to the United States or the United Kingdom to study. I think it would also be good if they made Japan one of their options. In fact, we did have one German postdoctoral researcher with us who later became a principal investigator (PI) upon his return to Germany. We need to strengthen the RIKEN brand and create an environment where researchers keep turning out excellent papers. In that way, those researchers who produce quality papers during their time at RIKEN will have an image as researchers who are not only quite competent in English but also capable of engaging in research with an open mind.

The Plant Science Center currently is at the forefront of biochemistry worldwide. Japanese are known for their special techniques for measuring minute amounts of compounds like metabolomes or hormones and, because of its long history in agricultural chemistry and chemistry in general, RIKEN is particularly strong in these areas. Many researchers from around the world come to Japan to learn these techniques. In that respect, I believe PSC offers some unique facilities and research areas that no other institution in the world can offer.

Shimizu: We need to promote these unique features more at an international level, so that people will feel they must come to RIKEN and PSC for their research.

Shirasu: You're right. It will take some time but sending out information is vital. It is only recently that we've been able to establish this kind of platform and begin to turn out a significant number of papers. PSC has risen in status internationally, so it has been well worth the effort. There are many advantages in having talented postdoctoral researchers come from overseas to PSC. To begin with, it provides opportunities to work with laboratories overseas and to expand our network in a more dynamic manner than if our research activities were confined to working with Japanese researchers here in Japan.

Like our joint research with the Max Planck Institute and other institutions, we can cooperate with world hubs in joint initiatives. In the area of plant research, there are a number of very prestigious centers in the world and, as a hub, PSC should cooperate with these centers, not just in name but in meaningful relationships. As researchers of these centers move about and continue their joint research with each other, it is important for us to hire them. A culture will also develop where it is taken for granted that science is conducted in English among Japanese researchers, who see English as a vehicle for conducting their work in science. People who are used to conducting lab meetings in English will also be able to deliver smooth presentations in English.

❖Foreign postdoctoral researchers at PSC

Yunike SHIMIZU
Research Personnel Support Section
Global Relations Office, RIKEN

❖——**The FPR Program and RIKEN's Internationalization**

Fiscal year	Total number of staff	No. of foreign researchers at RIKEN	Ratio of foreign researchers to total number of research staff	No. of FPRs	Foreigners – FPRs	Year-on-year change in number of foreigners (excluding FPRs)	Ratio to total number of research staff (excluding FPRs)	Ratio of FPRs to all foreigners at RIKEN
H18	2853	260	9.11%	0	260		9.11%	-
H19	2671	256	9.58%	0	256	-4	9.58%	-
H20	2538	241	9.50%	17	224	-32	8.83%	7.05%
H21	2552	288	11.29%	36	252	28	9.87%	12.50%
H22	2656	332	12.50%	47	285	33	10.73%	14.16%
H23	2686	352	13.10%	50	302	17	11.24%	14.20%

Shirasu: I would like to create opportunities for our researchers to become more proficient in English through day-to-day communication. The greater their proficiency, the easier it will be for them to prepare papers in English. We have some researchers who are extremely capable in conducting experiments but miss out on a lot of opportunities because they cannot write papers in English. Another important skill is the ability to collect information. When researchers attend academic conferences overseas, it is important to know how to source information. When no new information is forthcoming from presentations at an academic conference, they have to take the initiative to go visit some labs, make friends with other scientists and on occasion socialize by going out for a few drinks together. If they don't develop skills in forming relationships and gathering information, I think they will have a hard time.

A Place where Researchers can Pursue Their Aspirations

Shimizu: Under the present FPR program, the 30% allocation of foreign researchers based on the approximate 150 places originally established for Special Postdoctoral Researchers is spread across the labs on a mandatory basis. Of course, the ideal situation would be to recruit a certain percentage of foreign researchers without fail and have all candidates compete on the same playing field. To some extent, for the time being however, I feel that perhaps we need to direct our efforts to boosting our numbers on a compulsory basis, as you suggested.

Shirasu: It may not be fair unless the 30% of the people on the selecting side are also foreigners (laugh). Increasing the number of PIs is another important area where we need to make efforts.

Shimizu: The fact that RIKEN employs foreign PIs as Initiative Research Unit Leader also sends out an important message, I believe.

Shirasu: So, essentially, the challenges for us are to create an attractive environment and to change people's mindset through efforts on a daily basis. If we can attract foreign PIs who can be outstanding examples, others will want to follow in their footsteps. It would also be wonderful if we could have something like an exchange program for postgraduate students.

Shimizu: Actually, right now we are planning a series of "RIKEN Day" events overseas where we will hold joint symposiums with professors and students. As part of the program, we hope to encourage research at RIKEN as a career option for students and postdocs. If we can use this event in tandem with PSC's initiatives at internationalization to date, it could lead to the internationalization of RIKEN as a whole.

Shirasu: To a certain extent, RIKEN has already established an environment that no other university or research institute offers. I would like researchers who come to RIKEN to understand that if they make the most of their time with us, they will be able to take their research to the next level. We are very eager to gather many serious researchers at PSC. We would be interested in talking to aspiring young scientists who may not be able to go overseas at the moment but who have future ambitions to do so after hearing about our institution.

[Metabolomics Research Division]

Metabolomics and Metabolic Genomics Research

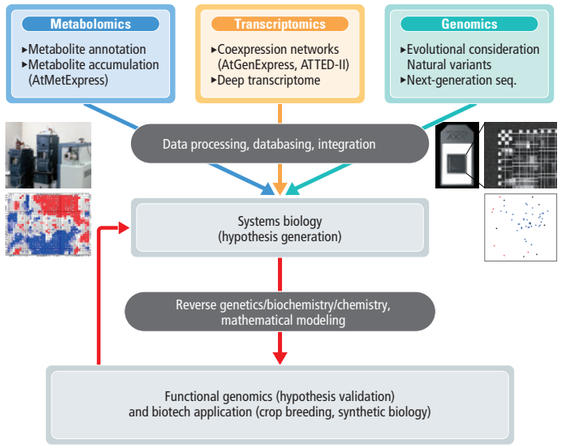
Research in plant metabolomics is of particular importance today because of the contribution of diverse metabolites to the usefulness of plants. At the Plant Science Center research in metabolomics and metabolic genomics is aimed at understanding and applying matter production systems in plants through integrated omics including bioinformatics.

PI [Principal Investigator]
[Metabolomic Function Research Group] Kazuki SAITO
[Metabolic Systems Research Team] Masami Yokota HIRAI
[Advanced NMR Metabomics Research Unit] Jun KIKUCHI
[Metabolome Informatics Research Team] Masanori ARITA

Importance of Metabolomics Research

One of the so-called omics sciences, metabolomics is the systematic identification and quantification of metabolites. Diverse metabolites contribute to the usefulness of plants in food, medicine, health function components, and raw materials in industry and energy. Therefore, metabolomics research in plants is particularly important.
The integration of metabolomics with techniques such as transcriptomics enables the scope of research to extend to functional genomics science, which identifies new gene functions leading to application to biotechnology and synthetic biology. In the same way, the integration of metabolomics with mathematical science allows for expansion of the scope of research to systems biology. Therefore, metabolomics has the potential to make a significant contribution to sustainable biological resources, and human survival and health. It was against this background that metabolomics research at the Plant Science Center commenced in 2005.

Diagram: From Metabolomics to Systems Biology



Establishment of a Platform for Metabolomics Research

Metabolomics consists of three main areas: 1) instrumental analysis of metabolites, 2) bioinformatics, and 3) integration and expansion to genome biology. The Metabolomics Research Division constructed a research platform to organically link these three areas and succeeded in launching a world-first analysis platform in metabolite profiling. This platform consists of two pillars: mass spectrometry (MS) with high sensitivity and specificity, and nuclear magnetic resonance (NMR), which has the advantages of quantitative and non-invasive performance.
In MS analyses, we have established the world's most comprehensive MS platform by linking and combining non-target mass analyses to a number of high-performance separation systems (gas and high-speed liquid chromatography, capillary electrophoresis). By further combining wide target analysis through robotics, we achieved further high-throughput and quantitative performance. In NMR analysis, we have also developed software for the automatic assignment of metabolome signals and multidimensional NMR metabolomics.
Since the inception of the Plant Science Center, we have devoted significant efforts to the development of bioinformatics research because our mission was to build a metabolomics platform not only for RIKEN and Japan but a platform that would lead the world in metabolomics. Therefore, we developed databases and analysis software that would also contribute to the world research community. The results of this initiative are the Platform for RIKEN Metabolomics (PRIMe) website, an integrated metabolomics portal, and a wide range of databases and analysis softwarethat are stored there.
Since 2010, with support in the form of equipment from the Leading Edge Research Infrastructure Programme, this metabolomics platform that integrates metabolite analysis and bioinformatics has been contributing significantly to the promotion of research in Japan and overseas as a leading center of metabolomics research led by plant science researchers in Japan.

Contribution to Functional Genomics Science

It is believed that plants have anywhere from 200,000 to one million kinds of metabolites, and the source of their chemical diversity is hidden in their genes. Therefore, one of the main objectives of metabolomics research is the study of functional genomics, which identifies the gene functions involved in plant functions. The Plant Science Center has a wide range of genome research resources based on *Arabidopsis thaliana*, which researchers have been able to use effectively.
We elucidated the linkages between genes and metabolites based on co-occurrence from mutant and stress-treated plant metabolomes, integrated transcriptome analyses, and publicly-available transcriptome data. We then proceeded to comprehensively identify gene functions and elucidate gene-to-metabolite networks through biochemical research using reverse genetics analyses and recombinant proteins based on mutants of the genes we identified. With this method we made significant strides using *Arabidopsis thaliana* and, following on from these positive results, we achieved further success by expanding our research to various agricultural crops including rice and medicinal plants.

Main Research in Metabolomics and Metabolic Functions Over the Past 8 Years

2006	● Discovery of a transcription factor that regulates "sulfur metabolism" in plants
2007	● Discovery of an enzyme that determines the structure of plant flavonoids ● Discovery of a new gene that causes cruciferous vegetables to produce cancer-inhibiting components ● Commencement of full-scale metabolomic profiling using the world's largest NMR facility ● Elucidation of plant metabolic networks using metabolomic profiling
2008	● Elucidation of plant's self-resistance mechanism to anti-cancer substance produced by plants ● Discovery of a new biosynthetic route of plant anti-oxidative flavonoids ● Identification of an enzyme gene that synthesizes a component of a natural low-calorie sweetener ● Preparation of a spectral library of tandem mass spectrometry for plant secondary metabolites ● Development of "bird's-eye view" analysis technology for metabolic pathways of all living organisms including plants and animals
2009	● Discovery of a new sterol biosynthetic pathway for plant sterol, the existence of which had been denied for 30 years ● Discovery of a new gene key to sulpho-lipid synthesis through lipid metabolome analysis ● Development of a real time analytical method for whole metabolite in the process of microorganism fermentation ● Elucidation of the close relationship between the plant circadian clock and mitochondrial functions ● Development of a new method of standardization for analytical data
2010	● Discovery of new facts about site-specific secondary metabolite biosynthesis in plants ● Development of a new NMR assessment technique for metabolized bio-resources mixtures for effective use of unutilized metabolites ● Study of taste and fragrance-producing components of dadachamame bean using metabolome analysis
2011	● Tracing of bacterial interactions using RIKEN's unique analysis of metabolic dynamics ● Elucidation of metabolic balance adjustment function of rice cytosolic glutamine synthase ● Objective assessment of genetically-modified crop using metabolomics ● Confirmation for the first time of the localization and dynamics of algae-produced metabolites within a single cell ● Discovery of glycosyltransferase genes involved in the accumulation of plant pigment anthocyanin ● Discovery of an enzyme gene for synthesizing pharmaceutical component in a rare herbal plant licorice
2012	● Comprehensive study to shed light on genetics of brown rice metabolism ● Elucidation of causal genes of "bitter beans"

Application to Crop Plant Biotechnology

In addition to identifying gene functions, metabolomics research opens pathways for the broad application of research results in areas such as crop breeding, biotechnology, and synthetic biology of useful substances. Some specific examples of applications are metabolome QTL analysis of major crop products including rice, regressive prediction of agricultural traits through metabolomic analysis, biotechnological production of useful secondary metabolites (glucosinolate, polyphenol, etc.), and metabolic function research for woody biomass, bioenergy crops and algae.
Furthermore, the application of metabolomics is already being demonstrated in broad, diverse areas such as substantial equivalence assessment of genetically-modified tomatoes, the analysis of single cells and vacuoles, plant triterpene production using enzymes, bioplastic material production using photosynthetic bacteria, and the application of NMR metabolomics in medicine.

New Developments and Challenges

Although metabolomics research has achieved significant results in plant science, there are still some areas which need to be addressed such as: (1) improvement in metabolite annotation, (2) dynamic profiling in areas such as metabolic flux, channelling, and imaging, etc., and (3) integration with mathematical science in areas such as metabolic simulation.
In the future, metabolomics research is expected to display its formidable power not only in basic research in areas such as the identification of new gene functions and systems biology but also in areas of research that affect our everyday lives such as the production of useful materials in green innovation and life innovation (industrial and biofuel materials, medicine and health-promoting compounds, etc.), and in improving food yields and crop breeding.

[Functional Genomics and Bioinformatics]

Developing Mutant Resources and Information Platforms

In functional genomics and bioinformatics research, we have collected mutant and gene resources that form an important platform for profiling genes in the research of the model plant *Arabidopsis thaliana*. We have elucidated genomic networks involved in light environment and stress responses. To expand the scope of our research to useful plant crops, we have developed similar databases for various plant species.

PI [Principal Investigator]
[Plant Functional Genomics Research Group]——**Minami MATSUI**
[Plant Genomic Network Research Team]——**Motoaki SEKI**
[Integrated Genome Informatics Research Unit]——**Tetsuya SAKURAI**

Progress in Research Over the Past Seven Years

The Plant Functional Genomics Research Group, Plant Genomic Network Research Team, and the Integrated Genome Informatics Research Unit, which make up functional genomics and bioinformatics, have made a start from the Plant Functional Genomics Research Group in the RIKEN Genomic Sciences Center (GSC) in 1999, and commenced the production of mutants of the model plant *Arabidopsis thaliana*, the collection of full-length cDNA gene information and the development of a database for this, and the provision of resources and data to researchers in Japan and overseas.

In 2006, the Plant Functional Genomics Research Group of the RIKEN Plant Science Center (PSC) was established. Since then, this group has been responsible for the production of gain-of-function resources for the genetic analysis of *Arabidopsis*, and has produced and analyzed a total of 100,000 activation tag lines and various FOX lines (full-length cDNA over expressors), which will be discussed later. In cooperation with the RIKEN BioResource Center (BRC), the PSC provides these resources to researchers in Japan and overseas. Using these resources, the group has also conducted research on the response of plants to the light environment.

Overview of the Plant Functional Genomics Research Group

The Plant Functional Genomics Research Group has been promoting the production of *Arabidopsis* gain-of-function lines. At the GSC, our group developed approximately 60,000 activation tag mutant lines and a database for these. We also developed a proprietary FOX line, which is a gain-of-function mutant *Arabidopsis* line (*Arabidopsis* FOX line) where the gain of function is forcefully conferred through over-expression of *Arabidopsis* full-length cDNA.

In joint research with the National Institute of Agrobiological Sciences (NIAS) and the Research Institute for Biological Science (Okayama Prefecture) which commenced in 2005, we have also developed a functional analysis platform for various plant species through the production of a rice-FOX *Arabidopsis* line (rice-FOX line) for conducting functional analysis using rice full-length cDNAs.

Using rice-FOX lines, we identified high-accumulation lines for drought tolerance, high-temperature tolerance, disease resistance, hormonal mutations and secondary metabolites, and performed rapid identification of the causal genes. We also jointly established a database with the Integrated Genome Informatics Research Unit and provided it to the public. In a joint research project with the National Institute of Advanced Industrial Science and Technology commencing in 2007, we promoted the development of new gain-of-function lines by collecting about 2,000 transcription factor genes from *Arabidopsis* and produced function-inducible transcription factors lines. In joint research with the Gene Discovery Research Group, we also engaged in the production of high-expression lines of peptide proteins.

As a laboratory theme, we have been researching how plants interpret the light environment to conduct morphogenesis, and in this research we have been utilizing various resources. From our research on light reception and the plant cell cycle, we found that CYCA2;1 and CYCA2;3 play key functions in the endoreduplication of plants.

We also undertook research to isolate an *Arabidopsis* FOX line which displays a distinctive blue-light morphology, and new genes from an integrated transcription factor line. In addition, we engaged in the comprehensive collection and functional genomics analysis of F-BOX proteins involved in specific protein decomposition important in various types of physiology [Diagram].

At the RIKEN Biomass Engineering Program established in 2010, we are responsible for research as the Synthetic Genomics Research Team. This team will take part in an international collaboration with Malaysia and other countries to develop basic technologies for the production of biomaterials utilizing the light reception of plants and using genomic analysis techniques and gene induction techniques as well as integrated gene co-expression systems in plants (IRES).

Overview of the Plant Genomic Network Research Team

We have explored the mechanism of RNA and epigenetic regulation, and new peptides involved in environmental stress responses. We found that antisense strand RNA is produced by RDR (RNA-dependent RNA polymerase) under environmental stress conditions. We also found that mutants of *Arabidopsis* Histone Deacetylase HDA6 showed drought stress tolerance through activation of acetate biosynthesis pathway. We demonstrated that drought stress tolerance can be enhanced by addition of acetate before drought stress treatment. In addition, we found that overexpressors of several stress-inducible small ORFs showed stress tolerance phenotype.

We have developed cutting-edge genome technologies and advanced gene identification and functional analysis of genes in joint research with domestic and oversea collaborators. We established a cassava functional genomics platform of international standard and advanced cassava molecular breeding in collaboration with Colombian, Thai and Vietnamese researchers.

Integrated Genome Informatics Research Unit

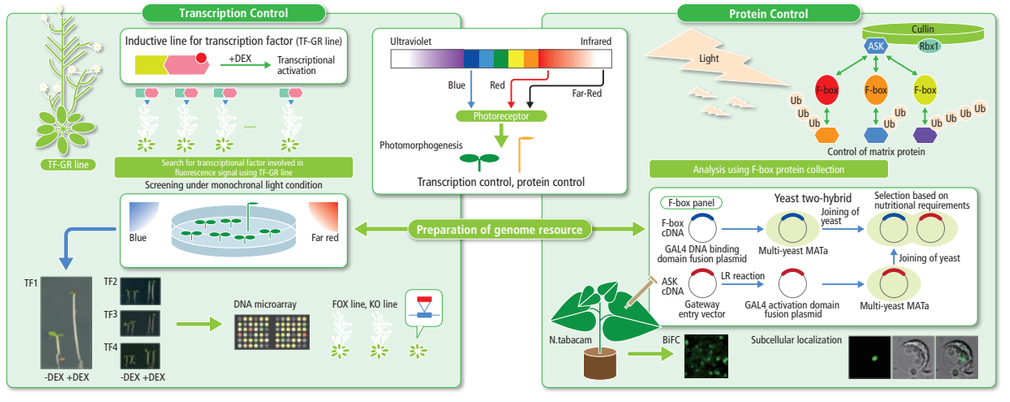
Utilizing sequence information including expressed sequence tags (EST), we have been focusing our research on understanding various gene functions in plants and the overview of genomes. To promote the development of research resources for trees and crops and the advancement of genomics research, we collected full-length cDNAs of poplar, soybean, cassava, and etc. and analyzed their sequences. Moreover, we provided the sequence information and results of our analyses to the public as databases on the Internet.

We have also contributed to the promotion of research related to the above areas through analyses and the development of databases for soybean genome decoding, genetic map integration for wheat (TriMEDB), full-length protein code sequencing (TriFLDB), phenotypes of various *Arabidopsis* mutants (RAPID, Chloroplast Function Database, RiceFOX), and transcripti on factors (LegumeTFDB, GramineaeTFDB, TreeTFDB). We developed and assisted metabolomics-related tools (PRIMe).

❖——Main Research Over the Past 7 Years

01	Investigation of genes using gain-of-function mutants involved in photoperception and cell cycles	09	Identification of new peptides involved in drought, cold, high-salinity, and high-temperature stress responses
02	Production of a total of 100,000 gain-of-function mutants in activation tagging lines, *Arabidopsis* FOX lines, and rice-FOX lines	10	Collection of full-length cDNAs in various crops, and transcriptome analysis
03	Collection of *Arabidopsis* transcription factors, production of function induction transformation lines, and profiling of transcription factors responsible for photoperception	11	Development of functional genomic analysis platform in cassava, and advancement of molecular breeding
04	Collection of F-BOX proteins responsible for protein decomposition, and comprehensive analyses of interactions	12	Epigenome and Transcriptome analysis using next generation sequencer(a project of the Japan Advanced Plant Science Research Network)
05	Development of multi-gene expression systems in plants	13	Promotion of research resource development for trees and crops, and genomics research
06	Management of transformation network for the promotion of crop research	14	Integration of soybean and wheat genetic mapping
07	Analysis of RNA and epigenetic regulatory mechanism involved in drought, low temperature, high-salinity, high-temperature stress and ABA responses	15	Construction of database for *Arabidopsis* mutant organism expression traits
08	Analysis of transcriptional and post-transcriptional regulation mechanisms through chromatin remodelling and RNAs	16	Support in the development of metabolomic tools

[Diagram]——Genomic Resource Platform for Comprehensive Analyses



[Growth Regulation and Productivity Systems——1 ▶ Growth Regulation Research Group/Dormancy and Adaptation Research Unit]

Elucidating Plant Hormone Biosynthesis and Signal Transduction

The Growth Regulation Research Group engages in efforts to shed light on the biosynthesis of plant hormones such as auxins, gibberellins, abscisic acid, and strigolactones which regulate plant growth and differentiation. Through this research, we are also contributing to improvement in plant productivity.

PI [Principal Investigator]
[Growth Regulation Research Group]——Yuji KAMIYA
[Dormancy and Adaptation Research Unit]——Mitsunori SEO

Progress of the Growth Regulation Research Group (Growth Physiology) Over the past 13 years.

Established in 2000, the Growth Regulation Research Group originally had a two-team structure consisting of the Laboratory for Cellular Growth and Development (Yuji Kamiya, PI) and the Laboratory for Reproductive Growth Regulation (Eiji Nambara, PI). The Laboratory for Cellular Growth and Development promoted biosynthesis and metabolic research of gibberellins (GAs) using *Arabiodopsis* seeds, which require GAs for germination, and identified the regulatory mechanisms of the main GA biosynthesis enzymes. Focusing on dormancy, the Laboratory for Reproductive Growth Regulation promoted research on the metabolism of abscisic acid (ABA) and the profiling of gene expression, and elucidated ABA inactivation enzyme genes and their functions.

Following an organizational restructure, the group assumed a three-team structure for promoting projects since 2005: the Growth Regulation Research Group (Yuji Kamiya, PI), the Dormancy and Adaptation Research Team (Eiji Nambara, PI), and the Cellular Growth and Development Research Team (Shinjiro Yamaguchi, PI). In addition to his work on GA research, in 2008 Dr. Yamaguchi identified strigolactones as a new plant hormone that regulates shoot branching. This discovery of the function of strigolactones as a plant hormone was an exciting result.

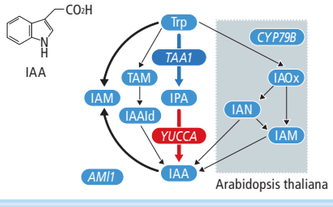
In 2011 Dr. Yamaguchi moved to Tohoku University to take up a position as professor there. Dr. Hiroyuki Kasahara, Senior Research Scientist of the Growth Regulation Research Group, through his research in functional analysis of the *yucca* gene, succeeded in identifying the biosynthesis pathway of auxins, which had remained a mystery for over half a century. Dr. Kasahara had been appointed as a Sakigake research scientist just prior to 2011.

After team leader Dr. Nambara took up a position at the University of Toronto in 2008, the group welcomed Dr. Mitsunori Seo from France and reorganized the Dormancy and Adaptation Research Team as the new Dormancy and Adaptation Research Unit. As head of this unit, Dr. Seo developed a unique hormone transporter isolation method using a plant hormone receptor complex and discovered a new ABA transporter involved in nitrogen metabolism. Our group has contributed to the world through plant hormone research over the past 13 years.

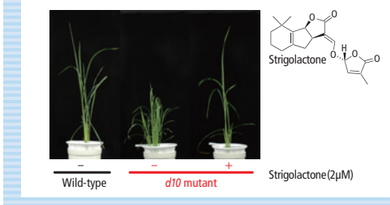
❖——Main Research of the Growth Regulation (Growth Physiology) Research Group

01	Research on the regulation of gibberellin biosynthesis, its reception and signal transduction
02	Research on abscisic acid (ABA) biosynthesis and metabolism
03	Studies on the regulation of ABA (regulation of biosynthesis, biosynthesis sites and transport)
04	Identification of factors involved in lateral bud dormancy and seed dormancy
05	Transcriptome analysis of seeds
06	Research on biosynthesis and regulation of jasmonic acids, brassinosteroids and auxins
07	Development of a simultaneous hormone analysis system, high-sensitivity analysis of hormones (which had been difficult to measure with the use of conventional methods), and measurement of intermediates
08	Chemical genetics approach for identification of inhibitors of isoprenoid biosynthesis and secondary metabolites in plastids
09	Role of the non-mevalonate pathway in diterpene biosynthesis, and production of useful materials
10	Functional analysis of P450 genes involved in hormone biosynthesis
11	Development of growth regulation technologies based on the regulation of plant hormone biosynthesis
12	Development of growth regulation technologies based on plant hormone-related genes and chemicals
13	Identification of new signaling molecules that regulate plant growth and development including strigolactones

[Diagram 1]——Auxin Biosynthesis Pathways



[Diagram 2]——Regulating of Shoot Branching by Strigolactone



Plant Science Center has adopted an omics approach in expression analysis of all hormone-related genes from its establishment. Since the metabolomics research group began participating in the PSC in 2005, we have been promoting hormonome research. In hormonome research, we conduct high-sensitive simultaneous analyses of hormones and their intermediates using LC-MS/MS. We integrate a high-sensitive analysis system with biosynthetic studies of GAs, ABAs, brassinosteroids and jasmonic acid, which we have been working on for many years, and isolate enzymes involved in the biosynthesis of plant hormones and their genes before conducting functional analyses of these.

Dr. Kasahara took up the challenge of biosynthesis research on auxins in 2007, and not only achieved success in the expression of yucca enzyme functions but also identified the main auxin biosynthesis pathways [Diagram 1].

The joint research of enzyme inhibitors in auxin biosynthesis has significant potential in the development of plant growth regulators. GA biosynthesis enzyme inhibitors are widely used all over the world as environmentally friendly plant growth regulators.

Overview of the Cellular Growth and Development Research Team and Research Results

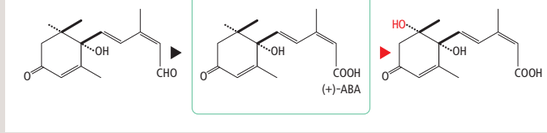
Dr. Shinjiro Yamaguchi has been promoting research in the light regulation of seed germination and also GA inactivation enzymes such as EUI and GA methyl transferase as well as research in new plant hormones. Although there were reports of the existence of a plant growth substance which regulated shoot branching in a number of plants through the biosynthesis of carotenoids, the chemical structure of this substance was not known. Using tillering dwarf rice mutants isolated by Dr. Junko Kyozuka of the University of Tokyo and *Arabidopsis* mutants, Dr. Yamaguchi and Dr. Umehara (Reseach Scientist) identified strigolactones for the first time as a new plant hormone that regulates shoot branching in plants [Diagram 2]. Strigolactone is also known as a hormone that induces hyphae branching in mycorrhizal fungi. Through this research, they found that there were differences in the structural activity of strigolactone in two bioactivities. In 2011 Dr. Yamaguchi moved as a professor at Tohoku University where he is continuing his research on strigolactone.

Laboratory for Reproductive Growth Regulation, and then Dormancy and Adaptation Research Unit

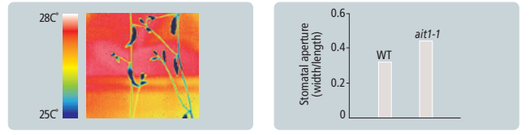
Viviparous germination in wheat that occurs during the rainy season in Japan is a serious problem in agriculture. If ABA could be made to accumulate in the wheat seeds, seed dormancy would become deeper and viviparous germination could be regulated. While it was known that the ABA degradation enzyme was a P450 enzyme, its gene was unknown. From out of the nearly 270 *Arabidopsis* P450 genes, Dr. Nambara along with Dr. Kushiro (Reseach Scientist) hypothesized that gene *CYP707* was involved in the metabolism of ABA based on reverse genetics approach, and they proved that *CYP707* is the P450 enzyme gene that catalyzes the hydration of 8′-postion of ABA. The *CYP707* deficient mutants exhibit deep dormancy, and viviparous [Diagram 3-A] does not occur. This was a major breakthrough from an agricultural perspective. Furthermore, the group also elucidated a new ABA-related factor from analysis of the ABA expression profile in seeds. Dr. Mitsunori Seo, the successor of Dr. Nambara, developed a method that involved the skillful use of ABA receptor complexes and also discovered a new ABA transporter [Diagram 3-B]. This method has significant application potential in the research of other plant hormones and transporters of physiologically active substances.

[Diagram 3]——Encoding of CYP707A Gene / New ABA Transporter

[Diagram 3-A]——*CYP9707A* encodes ABA 8′-hydroxylase



[Diagram 3-B]——Identification of an ABA transporter



[Growth Regulation and Productivity Systems——2 ▶ Plant Productivity Systems Research Group/Cell Function Research Team]

Identification and Utilization of Genes Useful for Improving Crop Productivity

With plant hormone research at the core, the Plant Productivity Systems Research Group engages in research to elucidate systems involved in production regulation, sink functions, and the effective transport of substances and undertakes research and development in techniques for use in production regulation. The Cell Function Research Team aims to elucidate networks that regulate plant organ and cell size using *Arabidopsis* as a model plant.

PI [Principal Investigator]
[Plant Productivity Systems Research Group]—Hitoshi SAKAKIBARA
[Cell Function Research Team]—Keiko SUGIMOTO

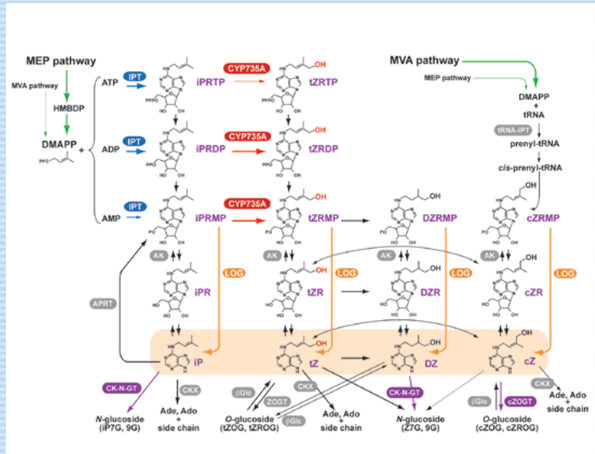
Progress of the Research Group Over the Past 13 Years

In October 2000 the Laboratory for Communication Mechanisms headed by Dr. Hitoshi Sakakibara was established to clarify mechanisms regulating plant growth in response to nitrogen nutrition using *Arabidopsis*. The scope of this research then expanded to include the elucidation of biosynthesis pathways of cytokinin effectively involved in the regulation of plant production functions and the study of the regulation mechanisms.
In April 2005, the team's name changed to the Biodynamics Research Team and the scope of research expanded to include rice and development of a comprehensive analysis platform for plant hormones. Focusing on the diversity of the growth environment of bryophytes, the team also engaged in research on heavy metal accumulation in moss and its application to industry.
In April 2010, the team became the Plant Productivity Systems Research Group and again expanded the scope of its research. The group currently engages in the elucidation of biomass production utilizing plant hormone action and mechanisms for optimizing plant growth in response to environmental changes.
In July 2007 the Cell Function Research Unit headed by Dr. Keiko Sugimoto was established to promote the identification of gene clusters involved in the regulation of plant organ and cell size. Continuing to pursue research as the Cell Function Research Team since 2012, the team aims to establish new methods for improving plant productivity by utilizing the results obtained from basic research.

❖——Main Research of the Research Group over the Past 13 Years

01	Identification and functional analysis of the key genes involved in cytokinin biosynthesis
02	Elucidation of cytokinin biosynthesis and its translocation mechanism in response to nitrogen nutrition
03	Structural biology based analysis of cytokinin biosynthesis and its signalling system
04	Elucidation of cytokinin biosynthesis pathway in phytopathogenic bacteria
05	Development of recovery technology for lead and gold using protonemal cells of bryophytes
06	Research on the circadian rhythm mechanism and plant growth regulation
07	Development and utilization of an highly-sensitive high-throughput plant hormone analysis platform
08	Elucidation of molecular mechanisms underlying plant cell proliferation and growth
09	Elucidation of molecular mechanisms underlying regulating pluripotency in plants
10	Elucidation and application of molecular mechanisms that determine organ size in plants

[Diagram 1]——Auxin Biosynthesis Pathways



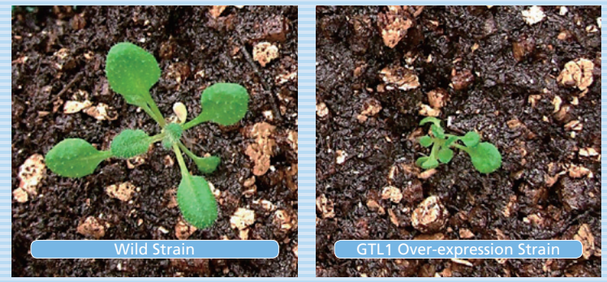
Overview of Research by the Plant Productivity Systems Research Group

The Plant Productivity Systems Research Group expanded its research to include improving the productivity of crops in areas such as altering the sink (growth and storage)-source (synthesis) balance and the effective transport and storage of assimilated products by focusing on the elucidation of cytokinin metabolism and its action. This research resulted in the identification of three enzyme genes responsible for biosynthesis: *IPT*, *CYP735A* and *LOG*. IPT is responsible for the primary reaction of the cytokinin biosynthesis pathway, CYP735A is responsible for playing a major role in the synthesis of highly-active cytokinin *trans*-zeatin, and LOG catalyzes the final step of cytokinin biosynthesis and also plays an important role in maintaining shoot meristem activity. The identification of *LOG* resulted in the discovery of a novel pathway of cytokinin activation. The group also identified a key *IPT* gene for regulating the biosynthesis of cytokinin in response to nitrogen nutrients and elucidated its regulation mechanism [Diagram 1]. The results obtained from this research are important in the regulation of cytokinin biosynthesis and are expected to contribute to improving the productivity of various crops in the future.
In addition to plants, some phytopathogenic bacteria are known to synthesize cytokinin. These bacteria infect plants and cause tumors formation as a result of uncontrolled synthesis of cytokinin. We demonstrated that *Agrobacterium*-derived IPT altered the cytokinin biosynthesis pathway to produce more *trans*-zeatin in the host plant, effectively causing the formation of tumors. The elucidation of this strategy for altering metabolic function in plant cells was a groundbreaking finding.
For deeper understanding of plant hormone actions, a comprehensive knowledge of distribution and concentrations of multiple hormones is essential. Therefore, we developed a highly sensitive high-throughput analysis platform of major plant hormones (six hormones, 45 molecular species), and discovered new genes through hormone QTL analysis utilizing this technology.
The productivity of plants is determined not only by genetic factors but also by environmental factors. Therefore, we engaged in research on environmental response mechanisms and the interaction of genes and the environment. As the main result of our research, our group demonstrated that PRR5, 7, 9 were transcription repressors in circadian rhythm regulation. We also determined that nitrate transporter 2.4 (NRT2.4) in *Arabidopsis* has a role in nitrate uptake under low external supply. Moreover, we found that protonemal cells of *Funaria hygrometrica* could accumulate metals such as lead and gold in large amounts and identified the modes of accumulation. Applying these findings to environmental purification and resource recovery for industrial purposes, we also developed a purifying system jointly with DOWA Holdings.

Research Overview of the Cell Function Research Team

The Cell Function Research Team engages in research to elucidate molecular systems that determine the size of higher plants by identifying gene clusters involved in the regulation of plant cell and organ growth. The team aims to apply its research outcome to establish new methods for improving crop productivity. We have recently discovered a new gene *HPY2* necessary for cell division and demonstrated that cell proliferation in plants is regulated by the SUMO protein produced by the genetic information of *HPY2*. The requirement of SUMO in the meristem development has never been shown before.
Until now, there has been little study on the mechanisms that actively regulate and arrest the growth of plant cells. We isolated and analyzed a mutant from the FOX (full-length cDNA over expressor) mutant collection of *Arabidopsis* in which leaf trichome cells grew to a gigantic size. Based on these results, we demonstrated that the plant-specific trihelix transcription factor GTL1 is involved in regulating ploidy-dependent cell growth. [Diagram 2]

[Diagram 2]——Overexpression of GTL1 Leads to Dwarf Plants



There are still many unknown aspects in the molecular mechanisms underlying plant dedifferentiation and regeneration, which are both used as a basis for technologies in the nursery, flower, and horticultural industries. The team identified a transcription factor *WIND1* which displays elevated expression after wounding. Strong expression of *WIND1* results in the formation of callus and these data together revealed the role of *WIND1* as a master regulator of wound-induced dedifferentiation in plants. These results may help establishing a new technology for plant propagation and production of useful materials based on the plant tissue culture.
What factors determine the size of plant organs is an important question in both basic and applied biology. In our investigation of plant organ-size control, our team identified a new enzyme involved in the inactivation of brassinosteroids as a factor that regulates plant organ size.

[Environmental Response and Adaptation——1/R&D Programs for PSC

▶ Gene Discovery Research Group, Signaling Pathway Research Unit, Regulatory Network Research Unit, R&D Programs for PSC]

Development of Crops with High Abiotic Stress Tolerance

Crop production under stress conditions has become an important issue as elevated temperatures, drought and other effects of global warming become increasingly evident because of accumulation of carbon dioxide. The Gene Discovery Research Group has begun to address this issue by exploring the acquisition of resistance in plants and the regulation of their growth as means of coping with abiotic stress caused by drought, elevated temperatures, salt damage, and nutrient-deficient soil. In research infrastructure activity named R&D Programs, the group is also developing a center-wide research platform and resources, and cooperating with external organizations.

PI [Principal Investigator]

[Gene Discovery Research Group]——Kazuo SHINOZAKI

[Regulatory Network Research Unit]——Lam-Son Phan TRAN

[Signaling Pathway Research Unit]——Ryoung SHIN

[R&D Programs for PSC]

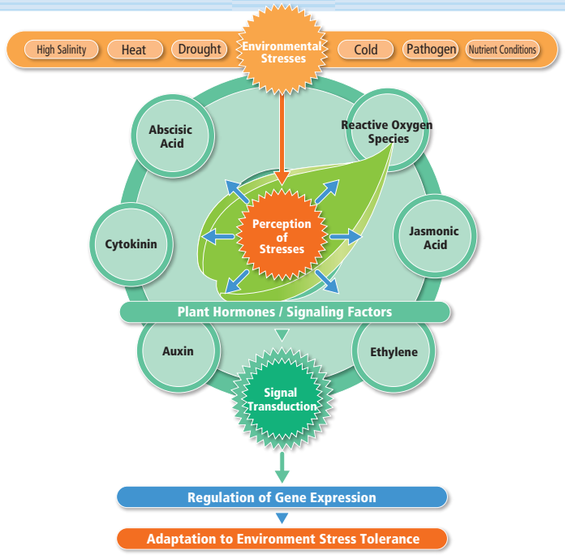
Progress of the Research Group Over the Past Eight Years

In 2005, the Gene Discovery Research Group was established along with the appointment of Dr. Kazuo Shinozaki as Center Director. Utilizing the model plant *Arabidopsis* and omics techniques, the group began its research by exploring important genes and later expanded its research to include the elucidation of gene co-adjustment networks.

The R&D Program, which supports the Plant Science Center as a whole, was established in 2007 to undertake three specific tasks: the development of common use microscopes and imaging technologies, development of technologies and support in genome sequencing and comparative genomic analysis, and the utilization of mutant resources for elucidating gene functions. In 2008 the Regulatory Network Research Unit headed by Dr. Ryoung Shin was established to promote research in signal transduction and metabolic regulation of plants in nutrient-deficient conditions. In 2009 the Signaling Pathway Research Unit headed by Dr. Lam-Son Phan Tran was established to undertake elucidation of genes related to plant adaptation to stress and plant hormone networks. Both units are also planning to undertake research that will lead to the development of crop species. With the inception of these two units, the Plant Science Center made significant progress in internationalization.

In tandem with the establishment of the Biomass Engineering Research Program in 2010, the Gene Discovery Research Group expanded the scope of its research to include the research and development of resource infrastructure relating to the improvement of soft cellulose biomass production. Aiming for stable agricultural production amid climate change conditions, the group analyzes systems by which plants respond and adapt to abiotic stress and nutrient-deficient environments and explores useful genes and the elucidation of their functions in efforts to demonstrate maximum productivity irrespective of the cultivation environment.

Elucidating a Stress Response Mechanism through Hormone Signaling



Overview of the Gene Discovery Research Group

The Gene Discovery Research Group promotes exploration of new genes and functional analyses of new genes involved in stress responses and resistance acquisition to elucidate plant response mechanisms to abiotic stress such as drought and salt damage. This group has developed stress-tolerant crops and trees and has achieved results in breeding drought-resistant crops in collaboration.

Through analyses of responses and adaptation to drought stress in plants at the genetic level, we have demonstrated the existence of a pathway mediated by plant hormone abscisic acid (ABA) and a pathway not mediated by ABA. In particular, we have demonstrated the involvement of protein phosphorylation in the ABA-dependent pathway. We have also devoted considerable efforts to elucidating relevant enzymes, and found that SnRK2 protein kinase plays a major role and is an important molecular switch that controls the downstream stress-responsive gene expression. The results achieved by the Gene Discovery Research Group have been highly evaluated and Group Director Dr. Kazuo Shinozaki was selected by Thomson Reuters as the world's 5th most cited researcher in 2011.

Overview of the Regulatory Network Research Unit

Since 2008 the Regulatory Network Research Unit has been elucidating components that regulate nutrient sensing and metabolic processes in plants to develop plants that will grow even in a nutrient-deprived soil environment. Dr. Shin has succeeded in isolating many candidate plants that will give us an insight into the signal transduction pathway for detecting potassium deficiency. To identify rice with nutrient deficiency tolerance, this unit undertook the screening of FOX (full-length cDNA over expressor) rice plants in nitrogen-deprived conditions and identified many candidate plants. Although it took considerable time to screen the mutant organisms, new, interesting mutants has been isolated. Utilizing these mutants, Dr. Shin is now conducting analyses of signal transduction cascades in plant nutrient sensing and nutrient deficient sensing.

Since 2012, this unit has also been engaging in the research and development of phytoremediation to remove radioactive cesium contaminated in areas surrounding damaged Fukushima nuclear power plants.

Research of the Gene Discovery Research Group Over the Past 8 Years

01	Exploration and analysis of regulatory factors and signaling factor involved in environmental stress responses	10	Elucidation of signaling networks regulating abitoic stress response and plant growth
02	Functional analysis of genes involved in abiotic stress tolerance, and development of drought resistant crops using genetic transformation	11	Biotechnology based on the knowledge of *Arabidosis*
03	Exploration and application of genes involved in plant productivity using a reverse genetic approach	12	Relationship between cytokinin metabolism and osmotic stress response
04	Development of environmental stress-resistant wheat and rice	13	Role of cytokinin-responsive phosphorelay network in osmotic stress regulation
05	Exploration and use of genes involved in improving soft biomass production using *Brachypodium*, a biofuel model herbaceous plant	14	Comprehensive analysis and comparative genome analysis of transcription factor in soybean and bean model plants
06	Dissection of signaling cascades in plant nutrient sensing and deficiency signaling	15	Management of bio-imaging technology and microscopy technologies
07	Isolation of nutrient-deficiency-tolerant rice plants	16	Collection of *Arabidopsis* knockout mutants for phenome analysis in gene discovery
08	Dissection of 14-3-3 regulated light signaling and 14-3-3's regulation	17	Comparative and evolutional genomics based on informatics
09	Role of cytokinin in environmental stress response, and the impact of osmotic stress on cytokinin metabolism	18	Comparative genomics and its application to crop improvement

Overview of the Signaling Pathway Research Unit

In 2009 the Signaling Pathway Research Unit launched a research project to demonstrate abiotic stress responses, the functions of plant growth regulators (brassinosteroids, cytokinins, ABAs, polyamines, etc.), in plant growth and performance, signal transmission, and crosstalk among hormones. At present Dr. Tran is conducting research mainly in functional analysis of a two-component regulatory system (TCS) related to cytokinin in osmotic stress response. In this research, this unit is focusing on the relationship of osmotic stress responses and crosstalk of cytokinin and ABA. To improve grain productivity, this unit is also directing its effort to the exploration of genes based on comparative genetic research using soybeans in adverse environments with the objective of developing stress tolerance in soybeans.

Overview of the R&D Programs for PSC

While supporting the Plant Science Center as a whole through the use of various technologies and resources, the R&D Programs has achieved many results in joint research projects. This group launched a microscope platform facility for analysis at the cellular level. This group also made effort to improve research efficiency and exchanges in techniques among research groups by centralizing costly microscopes and making them available to PSC as a whole. After several years of efforts, this group succeeded in establishing a superior microscope platform that benefits all groups and individuals engaged in research at the Center. The establishment of this platform is also resulting in the development of high-quality techniques at the molecular level.

In the R&D Programs, we have also promoted the development of genome analysis, an information platform for transcriptome analysis, and the collection of mutant resources for the functional analysis of genes for the advancement of research at the Center. We have also promoted phenotype analysis. The outstanding researchers and engineers who gather here play role in research and development at PSC.

[Environmental Response and Adaptation——2 ▸ Plant Immunity Research Group / Plant Proteomics Research Unit]

Research on Plant Immunity Systems for Sustainable Production

Pathogenic organisms in plants cause serious damage to agricultural production around the world. To mitigate this threat, the development of crop protection technologies that simultaneously demonstrate high efficiency and stability and a low environmental impact are essential. In Environmental Response and Adaptation–2, the Plant Immunity Research Group engages in research on plant immunity systems that will contribute to sustainable agricultural production, and promote the analysis of plant signaling networks through proteomics technologies.

PI [Principal Investigator]
[Plant Immunity Research Group]——Ken SHIRASU
[Plant Proteomics Research Unit]——Hirofumi NAKAGAMI

Progress of the Research Group Over the Past Seven Years

In October 2005, the Plant Immunity Research Group was established to contribute to sustainable agricultural production by improving the disease resistance mechanisms in plants. Initially, the Group Director, Ken Shirau, held a concurrent post at the Sainsbury Laboratory in the United Kingdom but in April 2006 commenced full-time research at RIKEN as his main occupation.

To elucidate the molecular structure of plant immune systems, the group focuses its research efforts on the discovery of useful genes, novel protein complexes, and the development of useful low-molecular weight compounds through the use of new methods such as genomics, proteomics, structure analysis, and chemical biology. This group has made progress in the area of proteomics in particular, and has developed an analysis method for plant proteins that undergo post-translational modifications such as phosphorylation. This method has been applied to rice and other grains. Based on the research results, the Plant Proteomics Research Unit, lead by Hirofumi Nakagami as a Unit Leader, was established in April 2010 and contributed to the promotion of proteomics at the Plant Science Center as well as plant research in Japan.

Characterization of Resistance Signaling Complexes

The elucidation of signaling pathways leading to disease resistance responses in plant-pathogen interactions will lead to revealing the full picture of immune response mechanisms in plants. For example, is there a correlation between plant immunity and the natural immune systems of animals? To understand this fundamental question, the research group explored the functional analysis of protein complexes, which hold the key to this question. The researchers in the group found that the protein known as SGT1, which is necessary for immune responses in both plants and animals, forms a complex with proteins known as RAR1 and HSP90, which play an important role in immunosensor functions for recognizing pathogen-derived substances. (Boter et al *Plant Cell* 19:3791-3804, Zhan et al *EMBO J* 27:2789, Kadota et al *EMBO* R 9:1209-1215, Shirasu *Annu Rev Plant Biol* 60: 139-164, Zhang et al *Mol Cell* 39:269-281) [Diagram].

The next challenge for the group will be to reveal how this protein complex, which is necessary for both plant and animal immunity, regulates immunosensors.

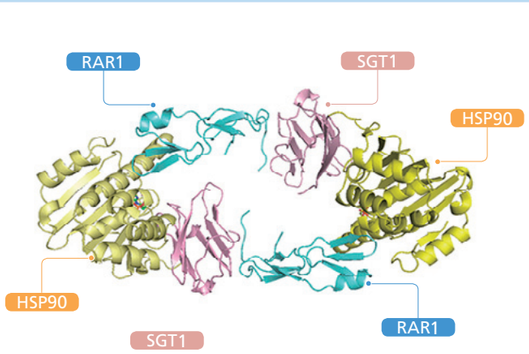
Research on Plant Immunity Regulation through Post-translational Modification

Many proteins are involved in gene expression of plant immunity, and many of these are regulated by post-translational modification. However, the overall image is still not clear. To tackle this theme, the researchers in the group adopted an approach for detecting the overall post-translational modifications in proteins (modified proteomes) as well as a method for elucidating individual modified proteins. For example, phosphoproteomes in *Arabidopsis* and rice plants (Sugiyama et al *Mol Sys Biol* 4:193, Nakagami et al *Plant Physiol* 153: 1161-1174) as well as ubiquitin-related proteomes, (Maor et al *Mol Cell Proteome* 6:601-610) were investigated. In addition, this group discovered that PUB protein cluster, which is a novel ubiquitin-related ligase, regulates plant immunity (Trujillo et al *Curr Biol* 18:1396-1401). Furthermore, the roles of MEKK1, a phosphorylation protein (kinase) (*JBC* 281: 36969-36976), and autophagy protein ATG, which performs ubiquitin ligase-like modifications (*Plant Cell* 21: 2914-2927) in plant immunity were elucidated. In the future the research group aims to demonstrate an overall image of plant immunity regulation through post-translational modifications.

Research of Pathogen Genomics

Pathogens suppress immune systems in plants and cause diseases. Thanks to revolutionary progress in genome sequencing technologies, determining these suppression mechanisms through the elucidation of pathogen genes is possible today. The group is currently focusing our attention on the anthracnose disease caused by *Colletotrichum* a pathogenic fungi, which is a very serious problem in Japan, and *Striga*, a parasitic plant causing serious damage to agriculture in Africa. Genome and transcriptome analyses of these pathogens were initiated.

❖3-Dimensional Structure of the Immune Signaling Complex PAR1-SGT1-HSP90 Site Formation



❖*Striga*, a parasitic plant that attacks sorghum, a major grain in Sudan

Among the anthracnose diseases in Japan, *Colletotrichum* on strawberry in particular causes damages in total about 3.5 billion yen annually, so finding an early solution to this fungus is an urgent issue. Our research group succeeded in analyzing the *Colletotrichum* genome and in identifying the genes that are likely to be involved in pathogenicity (Gan et al *New Phytologist*). By finding out which gene is predetermining the strength of pathogenicity, it is possible to develop a molecular marker that will enable early detection of the virulent fungi. This knowledge may also be helpful in the early discovery of pesticide-resistant fungi.

Striga, a parasitic plant, is causing serious damage in Africa, and research of Striga at the molecular level using genome and transcriptome analyses is already underway. The surprising discovery is that it not only acquires nutrients and water from the host plant but also genes (Yoshida et al *Science* 328: 1128). Detailed analyses are yet to be conducted but an understanding of the infection mechanism of the pathogen is likely to pave the way to establishing a counter strategy.

❖Main Research Over the Past 7 Years

01	Characterization of resistance signaling complexes
02	Isolation and characterization of novel proteins involved in plant immunity by proteomics
03	Molecular elucidation of parasitism of African witchweed *Striga*
04	Method development for post-translational modification analysis
05	Dissection of plant immunity signaling using proteomics methods
06	Analysis of pathogen genomes
07	Chemical biology of plant immunity

Representative Research Publications

01 *Arabidopsis* NPL1: A Phototropin Homolog Controlling the Chloroplast High-Light Avoidance Response

Science [vol. 291 no. 5511, pp. 2138-2141] **16 Mar. 2001**

Takatoshi Kagawa, Tatsuya Sakai, Noriyuki Suetsugu, Kazusato Oikawa, Sumie Ishiguro, Tomohiko Kato, Satoshi Tabata, Kiyotaka Okada, Masamitsu Wada

▸Individual plants require a particular optimum intensity of light for efficient photosynthesis, which becomes apparent in where they prefer to grow. Plants which favor strong light grow best in direct sunlight, while plants which favor weak light prefer shaded areas, such as under foliage. Light intensity in these preferred environments will also vary depending on the weather or time of day. In response to the intensity of incident light, chloroplasts can actually migrate within a cell; this migration is a system that plants use to maintain the optimal photosynthetic efficiency.

▸The research group isolated many mutants of *Arabidopsis Thaliana* which were defective in their chloroplast movement; the genome of *Arabidopsis Thaliana* has been completely sequenced and serves as a model plant. We selected four lines which don't show any movement of chloroplast even under strong light and searched for the gene that was causing this loss of function. This search led to the responsible gene, *NPL1*, whose base sequence had already been reported but its function was unknown. We demonstrated that the encoded protein of this gene is clearly involved in the recognition of strong light.

▸The chloroplasts in plants with this mutated gene do not move away to avoid strong blue light. Instead, they gather to move closer, which may also explain why chloroplasts gather under weak light. Two kinds of cryptomes have already been reported as blue light receptors. The results here clarify that the various phenomena exhibited by plants in response to blue light are co-regulated by at least four kinds of blue light receptors.

02 Cytokinin Oxidase Regulates Rice Grain Production

Science [vol.309 no.5735, pp.741-745] **29 July 2005**

Motoyuki Ashikari, Hitoshi Sakakibara, Shaoyang Lin, Toshio Yamamoto, Tomonori Takashi, Asuka Nishimura, Enrique R. Angeles, Qian Qian, Hidemi Kitano, Makoto Matsuoka

▸In the long history of plant breeding, humankind has selected and accumulated agriculturally useful traits resulting from various mutations. The desirable traits of individual rice cultivars are produced by the sum total of such mutated genetic loci. This set of mutated genes that produce a trait is called its quantitative trait locus (QTL).

▸In this research, we conducted QTL analysis to identify the genes which give rise to the difference in the rice grain productivity, and found QTL (*Gn1*) on the upper arm of chromosome 1 to greatly impact the grain yield. In the end, together with identifying gene for cytokinin oxidase /dehydrogenase (OsCKX2) as a responsible gene, we revealed the mechanism how the gene involves in determination of the grain yield. This is the first achievement that identified QTL directly involved in crop yield.

▸Furthermore, we successfully created a Koshihikari strain that is about 18% shorter and has a 20% increase in yield. Shorter rice leads to reduced lodging injury (stalks broken by wind and weather). QTL analysis enables future identification of responsible genes for agriculturally useful traits and transferring such genes to existing cultivars. Such "tailor-made molecular breeding" is expected to be the fundamental technology driving the "Second Green Revolution" to combat the possible food crisis which may strike as the world population increases.

03 Transcription switches for protoxylem and metaxylem vessel formation

Genes & Development [vol.19 no.16, pp.1855-1860] **15 Aug. 2005**

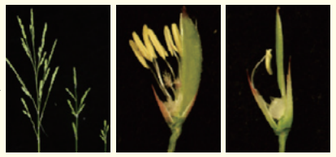
Minoru Kubo, Makiko Udagawa, Nobuyuki Nishikubo, Gorou Horiguchi, Masatoshi Yamaguchi, Jun Ito, Tetsuro Mimura, Hiroo Fukuda, Taku Demura

▸Most of the biomass on earth is derived from xylem vessel cells included in wood. In this research, we found many genes (about 200 genes) which are expressed in xylem formation by comprehensive expression analysis of approximately 23,000 *Arabidopsis* genes with a newly established xylem formation system of *Arabidopsis* cultured cells by our research group in order to identify the genes which regulate the xylem formation.

▸We focused on NAC-domain proteins which have been suggested to be involved in regulation of gene expression and analyzed the function of these genes in detail using *Arabidopsis* and poplar. We showed that two analogous NAC-domain proteins named VND5 and VND7 have the ability to differentiate cells which wouldn't naturally differentiate into xylem such as epidermal cells. Additionally, repression of the function of these genes disables the normal formation/development of xylem, which reveals that these are the master genes for xylem formation.

▸This marks the world's first results to identify the genes which are able to directly induce xylem formation. By analyzing in detail the entire gene expression network that VBD6 and VND control, it will be possible to artificially regulate the productivity and quality of biomass. This result is also expected to establish molecular breeding technology to realize super trees with enhanced productivity and quality.

04 Direct control of shoot meristem activity by a cytokinin-activating enzyme



❖Phenotype of *log* mutant

Nature [vol.445 no.7128, pp.652-655] **8 Feb. 2007**

Takashi Kurakawa, Nanae Ueda, Masahiko Maekawa, Kaoru Kobayashi, Mikiko Kojima, Yasuo Nagato, Hitoshi Sakakibara, Junko Kyozuka

▸Cytokinin is a plant hormone with crucial roles in plant growth and crop yield by repressing leaf senescence, activating photosynthesis, regulating apical dominance, and determining the number of rice grains. Generally, hormones are present at very low concentration. For this reason, plants usually synthesize the hormone's inactive precursors, which are activated as the need arises. The genes involved in the biosynthesis of cytokinin precursors were known prior to our work, but the gene functioning in the most important activation step of the precursors had yet to be discovered.

▸The research group discovered that the *LOG* gene, the responsible gene for log mutant of rice which causes abnormal formation of ears and flowers, encodes enzymes for cytokinin activation. That is, we revealed that the LOG protein made from this gene removes sugar phosphate from the cytokinin nucleotide to generate the active form of cytokinin in a truly novel fashion. The *LOG* gene works only in a limited group of cells in meristem tissue, which shows how finely the amount of active cytokinin is tuned in a plant.

▸By using *LOG* genes, it becomes possible to directly control the cytokinin activity inside the plant body. We expect that manipulating the functioning of *LOG* genes in various crops will greatly enhance agricultural productivity.

05 Inhibition of shoot branching by new terpenoid plant hormones

Nature [vol.455 no.7210, pp.195-200] **11 Sept. 2008**

Mikihisa Umehara, Atsushi Hanada, Satoko Yoshida, Kohki Akiyama, Tomotsugu Arite, Noriko Takeda-Kamiya, Hiroshi Magome, Yuji Kamiya, Ken Shirasu, Koichi Yoneyama, Junko Kyozuka, Shinjiro Yamaguchi

▸The pattern and extent of shoot branching of plants determine the above-ground plant shape, and ultimately influence the quantity and quality of flowers and seeds, and are thus agriculturally and horticulturally important traits. Adequate regulation of shoot branching is a key to maintain the survival strategy of plants in nature, as well as the quality of crops and yield in cultivated production.

▸The research team has analyzed mutants with enhanced shoot branching and shorter height, and found that a series of compounds called strigolactones act as a hormone to control shoot branching.

▸The research team proved that the these mutants that lack the gene for strigolactone biosynthesis are also more difficult to be infected by *Striga*. *Striga* parasitizes on the root of crops and deprives them of nutrients and water, which interferes with their growth.

▸We expect that this discovery will trigger further research on strigolactone and lead to development of a method for controlling shoot branching and also a method for inhibiting plant parasites, both of which affect crop yield.

06 phot1 and phot2 mediate blue light-induced transient increases in cytosolic Ca^{2+} differently in *Arabidopsis* leaves

Proc Natl Acad Sci USA [vol.100 no.14, pp.8583-8588] **8 July 2003**

Akiko Harada, Tatsuya Sakai, Kiyotaka Okada

▸We were the first in the world to reveal that calcium ions are a common signal for two blue light receptors, phototropin1 (photo1) and phototropin2 (photo2). We demonstrated that each receptor regulates calcium ion concentration differently.

07 Functional analysis of each blue light receptor, cry1, cry2, phot1, and phot2, by using combinatorial multiple mutants in *Arabidopsis*

Proc Natl Acad Sci USA [vol.101 no.8, pp.2223-2228] **24 Feb. 2004**

Maki Ohgishi, Kensuke Saji, Kiyotaka Okada, Tatsuya Sakai

▸We revealed the function of each of the four blue light sensors that are involved in plant growth. Cryptochrome1 and Cryptochrome2 are only involved in photomorphogenesis or regulation of gene expression, each of which takes a long time to respond to stimulation by light. In contrast, phototropin1 and phototropin 2 mainly regulate the movement response, which responds immediately to the light.

08 The *Arabidopsis* cytochrome P450 CYP707A encodes ABA 80-hydroxylases: key enzymes in ABA catabolism

The EMBO Journal [vol.23 no.7, pp.1647-1656] **7 Apr. 2004**

Tetsuo Kushiro, Masanori Okamoto, Kazumi Nakabayashi, Kazutoshi Yamagishi, Sayaka Kitamura, Tadao Asami, Nobuhiro Hirai, Tomokazu Koshiba, Yuji Kamiya, Eiji Nambara

▸We discovered which genes encode ABA 8'-hydroxylases, which are the key enzymes to activate the plant hormone abscisic acid (ABA) and also demonstrated that plants which have lost this gene lie deeply dormant.

09 *Agrobacterium tumefaciens* increases cytokinin production in plastids by modifying the biosynthetic pathway in the host plant

Proc Natl Acad Sci USA [vol.102 no.28, pp.9972-9977] **12 July 2005**

Hitoshi Sakakibara, Hiroyuki Kasahara, Nanae Ueda, Mikiko Kojima, Kentaro Takei, Shojiro Hishiyama, Tadao Asami, Kazunori Okada, Yuji Kamiya, Tomoyuki Yamaya, Shinjiro Yamaguchi

❖A crown galls formed by infection of a tomato by Agrobacterium.

▸We discovered that after *Agrobacterium* (a crown gall bacterium) infected a plant, it modifies the metabolism of the host by sending its proteins into plastids (e.g. chloroplasts); this invasion induces tumor formation.

10 ELONGATED UPPERMOST INTERNODE Encodes a Cytochrome P450 Monooxygenase That Epoxidizes Gibberellins in a Novel Deactivation Reaction in Rice

The Plant Cell [vol.18 no.2, pp.442-456] **Feb. 2006**

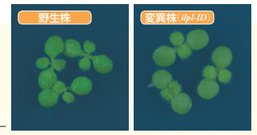
Yongyou Zhu, Takahito Nomura, Yonghan Xu, Yingying Zhang, Yu Peng, Bizeng Mao, Atsushi Hanada, Haicheng Zhou, Renxiao Wang, Peijin Li, Xudong Zhu, Lewis N. Mander, Yuji Kamiya, Shinjiro Yamaguchi, Zuhua He

▸We discovered a novel deactivation mechanism of gibberellins, a growth promoting hormone of plants. This is an epoch-making discovery that proves the existence of a novel mechanism for regulation of growth hormone in a specific organ of plants. Thus, we opened new avenues for technology that regulates growth of plants by using growth hormones.

11 INCREASED LEVEL OF POLYPLOIDY1, a Conserved Repressor of *CYCLINA2* Transcription, Controls Endoreduplication in *Arabidopsis*

The Plant Cell [vol.18 no.10, pp.2452-2468] **Oct. 2006**

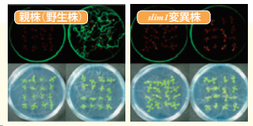
Takeshi Yoshizumi, Yuko Tsumoto, Tomoko Takiguchi, Noriko Nagata, Yoshiharu Y. Yamamoto, Mika Kawashima, Takanari Ichikawa, Miki Nakazawa, Naoki Yamamoto, Minami Matsui



❖Morphology of wild-type seedlings (left) and mutant seedlings (right). Mutants have bigger leaves compared to those of wild-type plants by about 30%.

▸We discovered a gene which regulates the amount of nucleic DNA in a cell and makes it possible to change the size of cells. The size of an organism is determined by the number and size of cells which constitute the organism; hence, the more DNA in the nucleus, the bigger plant cells become.

12 *Arabidopsis* SLIM1 Is a Central Transcriptional Regulator of Plant Sulfur Response and Metabolism



❖Isolation of *slim1* mutants by fluorescent imaging. Mutants have bigger leaves compared to those of wild-type plants by about 30%.

The Plant Cell [vol.18 no.11, pp.3235-3251] **Nov. 2006**

Akiko Maruyama-Nakashita, Yumiko Nakamura, Takayuki Tohge, Kazuki Saito, Hideki Takahashi

▸We analyzed *Arabiopsis* mutants with abnormal sulfur metabolism and discovered SLIM1, a transcription factor regulating the content of an organosulfur compound named Glucoraphanin; this compound exhibits anti-cancer effects. This discovery will be useful for applied research to enhance the productivity and utility of cruciferous plants.

13 The Mitogen-Activated Protein Kinase Cascade MKK3–MPK6 Is an Important Part of the Jasmonate Signal Transduction Pathway in *Arabidopsis*

The Plant Cell [vol.19 no.3, pp.805-818] **Mar. 2007**

Fuminori Takahashi, Riichiro Yoshida, Kazuya Ichimura, Tsuyoshi Mizoguchi, Shigemi Seo, Masahiro Yonezawa, Kyonoshin Maruyama, Kazuko Yamaguchi-Shinozaki, Kazuo Shinozaki

▸We discovered the MKK3-MPK6s cascade regulating the signaling of jasmonic acid, a key plant hormone for plants to respond to damage caused by insects and pathogens, and succeeded for the first time in the world to regulate the expression of genes involved in defense responses to insects and pathogens.

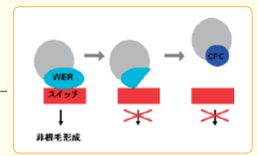
14 Omics-based identification of *Arabidopsis* Myb transcription factors regulating aliphatic glucosinolate biosynthesis

Proc Natl Acad Sci USA [vol.104 no.15, pp.6478-6483] **10 Apr. 2007**

Masami Yokota Hirai, Kenjiro Sugiyama, Yuji Sawada, Takayuki Tohge, Takeshi Obayashi, Akane Suzuki, Ryoichi Araki, Nozomu Sakurai, Hideyuki Suzuki, Koh Aoki, Hideki Goda, Osamu Ishizaki Nishizawa, Daisuke Shibata, Kazuki Saito

▸We discovered a key gene which regulates the biosynthesis of glucosinolates (mustard oil glycosides), anti-cancer compounds contained in vegetables such as broccoli. This is expected to lead to the creation of "functional vegetables" with high anti-cancer effects, or alternatively, to making glucosinolates in culture tanks of plant cells.

15 Functional Analysis of the Epidermal-Specific MYB Genes *CAPRICE* and *WEREWOLF* in *Arabidopsis*



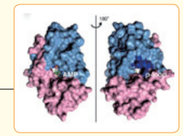
❖Evolution from WER to CPC

The Plant Cell [vol.19 no.7, pp.2264-2277] **July 2007**

Rumi Tominaga, Mineko Iwata, Kiyotaka Okada, Takuji Wada

▸We revealed that *CPC* genes which have the function to make root hair of *Arabidopsis* evolved from the *WER* gene which has the function of eliminating root hair. This will be useful to understand the complicated mechanism of the differentiation of epidermal cells into root hair, trichomes, stomata, etc.

16 Structural insight into the reaction mechanism and evolution of cytokinin biosynthesis


❖3D structure of IPT protein

Proc Natl Acad Sci USA [vol.105 no.7, pp.2734-2739] **19 Feb. 2008**

Hajime Sugawara, Nanae Ueda, Mikiko Kojima, Nobue Makita, Tomoyuki Yamaya, Hitoshi Sakakibara

▸We succeeded in performing 3D structural analysis of the synthase of cytokinin which is involved in disease and regulation of yield in plants. And we revealed the reaction mechanisms of cytokinin biosynthesis. By artificially changing the function of IPT, productivity of various crops is expected to improve.

17 Comprehensive Flavonol Profiling and Transcriptome Coexpression Analysis Leading to Decoding Gene–Metabolite Correlations in *Arabidopsis*

The Plant Cell [vol.20 no.8, pp.2160-2176] **Aug. 2008**

Keiko Yonekura-Sakakibara, Takayuki Tohge, Fumio Matsuda, Ryo Nakabayashi, Hiromitsu Takayama, Rie Niida, Akiko Watanabe-Takahashi, Eri Inoue, Kazuki Saito

▸We discovered a new pathway to transfer arabinose to flavonol in the biosynthesis of flavonoids, which are a major antioxidant for plants. We revealed the metabolomics network in detail. Further understanding will allow modified plants to produce essential ingredients for materials in medicine, food, and industry.

18 Negative Regulation of PAMP-Triggered Immunity by an E3 Ubiquitin Ligase Triplet in *Arabidopsis*

Current Biology [vol.18 no.18, pp.1396–1401] **23 Sept. 2008**

Marco Trujillo, Kazuya Ichimura, Catarina Casais, Ken Shirasu

▸We succeeded to identify three genes which negatively regulate the defense response of plants against pathogens such as bacteria or fungus. And we revealed that plants have a system to fine-tune the defense response by using this negative regulation. We expect that regulating this function will contribute to the development of disease tolerant crops.

19 Licorice β-amyrin 11-oxidase, a cytochrome P450 with a key role in the biosynthesis of the triterpene sweetener glycyrrhizin


❖The licorice root and the minced one that are used as a herbal medicine.

Proc Natl Acad Sci USA [vol.105 no.37, pp.14204-14209] **16 Sept. 2008**

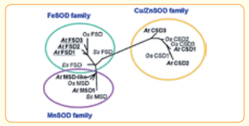
Hikaru Seki, Kiyoshi Ohyama, Satoru Sawai, Masaharu Mizutani, Toshiyuki Ohnishi, Hiroshi Sudo, Tomoyoshi Akashi, Toshio Aoki, Kazuki Saito, Toshiya Muranaka

▸We revealed the key enzyme gene for the biosynthesis of glycyrrhizin, a natural sweetener. Glycyrrhizin is extracted from the underground parts (turnip roots and rhizomes) of licorice, a legume, and is in demand, worldwide, as a natural sweetener and medicine.

20 A Heterocomplex of Iron Superoxide Dismutases Defends Chloroplast Nucleoids against Oxidative Stress and Is Essential for Chloroplast Development in *Arabidopsis*

The Plant Cell [vol.20 no.11, pp. 3148-3162] **Nov. 2008**

Fumiyoshi Myouga, Chieko Hosoda, Taishi Umezawa, Haruko Iizumi, Takashi Kuromori, Reiko Motohashi, Yuriko Shono, Noriko Nagata, Masahiko Ikeuchi, Kazuo Shinozaki



❖A phylogenic tree of *SOD* gene family

▸We revealed that two specific proteins which are involved in removing reactive oxygen species (ROS) form a heteromeric complex. This complex protects the chloroplast nucleoids from ROS, which are harmful for *Arabidopsis*. This is a necessary mechanism for the early development of chloroplasts, which are essential for plants.

21 Dual biosynthetic pathways to phytosterol via cycloartenol and lanosterol in *Arabidopsis*

Proc Natl Acad Sci USA [vol.106 no.3, pp.725-730] **20 Jan. 2009**

Kiyoshi Ohyama, Masashi Suzuki, Jun Kikuchi, Kazuki Saito, Toshiya Muranaka

▸Sterols are a vital compounds for life and exist universally among organisms. Their biosyntheses are believed to be different between animals and plants; however we discovered that one of the sterol biosynthesis pathways that plants have occurs via lanosterol which is known to as the sterol biosynthesis pathway in animals.

22 Genome-wide suppression of aberrant mRNA-like noncoding RNAs by NMD in *Arabidopsis*

Proc Natl Acad Sci USA [vol.106 no.7, pp.2453-2458] **17 Feb. 2009**

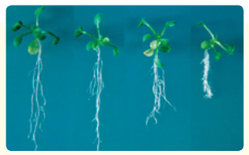
Yukio Kurihara, Akihiro Matsui, Kousuke Hanada, Makiko Kawashima, Junko Ishida, Taeko Morosawa, Maho Tanaka, Eli Kaminuma, Yoshiki Mochizuki, Akihiro Matsushima, Tetsuro Toyoda, Kazuo Shinozaki, Motoaki Seki

▸We revealed that NMD, a pathway to degrade aberrant mRNA, suppresses many mRNA-like nonprotein-coding RNAs (mlncRNAs) by detecting the RNA expression level of *Arabidopsis* genes with tiling array.

23 Biochemical analyses of indole-3-acetaldoxime-dependent auxin biosynthesis in *Arabidopsis*

Proc Natl Acad Sci USA [vol.106 no.13, pp.5430-5435] **31 Mar. 2009**

Satoko Sugawara, Shojiro Hishiyama, Yusuke Jikumaru, Atsushi Hanada, Takeshi Nishimura, Tomokazu Koshiba, Yunde Zhao, Yuji Kamiya, Hiroyuki Kasahara



❖Transgenic *Arabidopsis* plants that overexpress auxin biosynthesis genes (*TAA1* and *YUCCA*)

▸By using a cutting-edge mass spectrometer, we detected an intermediate in the synthesis of auxin, a plant hormone. This allowed us to understand the auxin biosynthetic pathway in plants, which had otherwise evaded elucidation.

24 A Chloroplastic UDP-Glucose Pyrophosphorylase from *Arabidopsis* Is the Committed Enzyme for the First Step of Sulfolipid Biosynthesis

The Plant Cell [vol.21 no.3, pp.892-909] **Mar. 2009**

Yozo Okazaki, Mie Shimojima, Yuji Sawada, Kiminori Toyooka, Tomoko Narisawa, Keiichi Mochida, Hironori Tanaka, Fumio Matsuda, Akiko Hirai, Masami Yokota Hirai, Hiroyuki Ohta, Kazuki Saito

▸We discovered a novel gene involved in the biosynthesis of sulfolipid, which exists in a wide variety of plant species. We succeeded to identify the function of sulfolipid and can now regulate sulfolipid biosynthesis by using the discovered gene. Regulating sulfolipid biosynthesis enables the development of plants tolerant to phosphate deficiency, which is a challenge we might face in future.

25 Impact of clock-associated *Arabidopsis* pseudo - response regulators in metabolic coordination

Proc Natl Acad Sci USA [vol.106 no.17, pp.7251-7256] **28 Apr. 2009**

Atsushi Fukushima, Miyako Kusano, Norihito Nakamichi, Makoto Kobayashi, Naomi Hayashi, Hitoshi Sakakibara, Takeshi Mizuno, Kazuki Saito

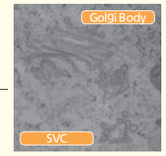
❖Revealed output function of discovered PRR9, 7, and 5

▸By comprehensive analysis of plant metabolites, we discovered that the circadian clock in cells have close relationship with the function of mitochondria, which are organelles that generate necessary cellular energy. This relationship has been suggested in animals and fungi, but this is the first discovery in plants.

26 A Mobile Secretory Vesicle Cluster Involved in Mass Transport from the Golgi to the Plant Cell Exterior

The Plant Cell [vol.21 no.4, pp.1212-1229] **Apr. 2009**

Kiminori Toyooka, Yumi Goto, Satoru Asatsuma, Masato Koizumi, Toshiaki Mitsui, Ken Matsuoka



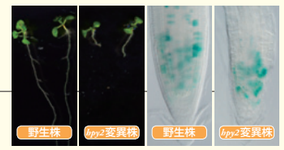
❖SVC & Golgi Body

▸As a plant grows, the massive amount of cell wall material that is synthesized by Golgi machinery is secreted out into the extracellular space. We discovered that the cellular transport machinery is a clustered structure of secretory vesicles, which are characteristically found in plant cells. We termed the machinery "Secretory Vesicle Cluster".

27 SUMO E3 Ligase HIGH PLOIDY2 Regulates Endocycle Onset and Meristem Maintenance in *Arabidopsis*

The Plant Cell [vol.21 no.8, pp.2284-2297] **Aug. 2009**

Takashi Ishida, Sumire Fujiwara, Kenji Miura, Nicola Stacey, Mika Yoshimura, Katja Schneider, Sumiko Adachi, Kazunori Minamisawa, Masaaki Umeda, Keiko Sugimoto



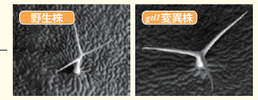
❖*HPY2* regulates cell division

▸We discovered a new gene *HPY2 (HIGH PLOIDY2)* that is necessary for cell division in multicellular organisms. We revealed that this gene also has an important role in regulating the activity of cell division. In the future, this will enable breeding of higher-yield crops.

28 The Trihelix Transcription Factor GTL1 Regulates Ploidy-Dependent Cell Growth in the *Arabidopsis* Trichome

The Plant Cell [vol.21 no.8, pp.2307-2322] **Aug. 2009**

Christian Breuer, Ayako Kawamura, Takanari Ichikawa, Rumi Tominaga-Wada, Takuji Wada, Youichi Kondou, Shu Muto, Minami Matsui, Keiko Sugimoto



❖*GTL1* has the function to suppress plant growth.

▸We discovered a new transcription factor GTL1 (GT2-LIKE 1) which suppresses plant cell growth. Using this discovery, we succeeded to make plant cells grow more than twice their normal size by reducing the level of GTL1. GTL1 is the first regulation factor that has been found to actively suppress plant cell growth.

29 Type 2C protein phosphatases directly regulate abscisic acid-activated protein kinases in *Arabidopsis*

Proc Natl Acad Sci USA [vol.106 no.41, pp.17588-17593] **13 Oct. 2009**

Taishi Umezawa, Naoyuki Sugiyama, Masahide Mizoguchi, Shimpei Hayashi, Fumiyoshi Myouga, Kazuko Yamaguchi-Shinozaki, Yasushi Ishihama, Takashi Hirayama, Kazuo Shinozaki

❖The mechanism of ABA signaling

▸We revealed the signaling pathway of abscisic acid (ABA), a plant hormone involved in the response to severe environmental conditions. In the future, various applications are anticipated, such as development of crops that are tolerant to drought, salinity, and cold, as well as improvement of seed stability or repression of pre-harvest sprouting.

30 Autophagy Negatively Regulates Cell Death by Controlling NPR1-Dependent Salicylic Acid Signaling during Senescence and the Innate Immune Response in *Arabidopsis*

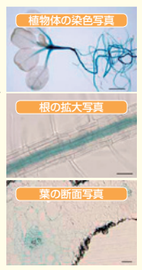
The Plant Cell [vol.21 no.9, pp.2914-2927] **Sept. 2009**

Kohki Yoshimoto, Yusuke Jikumaru, Yuji Kamiya, Miyako Kusano, Chiara Consonni, Ralph Panstruga, Yoshinori Ohsumi, Ken Shirasu

▸We revealed that autophagy, a cellular degradation and recycling system, negatively regulates the signaling of salicylic acid, a plant hormone. Autophagy suppresses senescence and programmed cell death in response to infection by a pathogen.

31 ABC transporter AtABCG25 is involved in abscisic acid transport and responses

❖Analysis of expression and localization *in planta*



Proc Natl Acad Sci USA [vol.107 no.5, pp.2361-2366] **2 Feb. 2010**

Takashi Kuromori, Takaaki Miyaji, Hikaru Yabuuchi, Hidetada Shimizu, Eriko Sugimoto, Asako Kamiya, Yoshinori Moriyama, Kazuo Shinozaki

▸We discovered AtABCG255, one of the transporters of abscisic acid (ABA), which makes plants tolerant to drought. We demonstrated that we are able to produce drought tolerant plants by regulating ABA in planta.

32 PSEUDO-RESPONSE REGULATORS 9, 7, and 5 Are Transcriptional Repressors in the *Arabidopsis* Circadian Clock

The Plant Cell [vol.22 no.3, pp.594-605] **Mar. 2010**

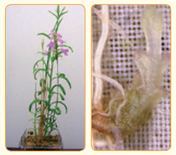
Norihito Nakamichi, Takatoshi Kiba, Rossana Henriques, Takeshi Mizuno, Nam-Hai Chua, Hitoshi Sakakibara

▸We found that three proteins PRR9, PRR7, and PRR5 involved in the internal clock in plants (circadian clock) have the function of repressing transcriptional activity. Through activity that is elevated particularly around dawn, they repress the transcriptional activity of *CCA1* and *LHY* genes, which are known to be related to the internal clock.

33 Horizontal Gene Transfer by the Parasitic Plant *Striga hermonthica*

Science [vol.328 no.5982, p.1128] **28 May 2010**

Satoko Yoshida, Shinichiro Maruyama, Hisayoshi Nozaki, Ken Shirasu



❖Parasite plant *Striga* on rice

▸By large-scale genome analysis of parasite plants *Striga*, we uncovered the first instance in which genes are horizontally transferred from nuclei of host plants to parasitic plants.

34 A small-molecule screen identifies new functions for the plant hormone strigolactone

Nature Chemical Biology [vol.6 no.10, pp.741-749] **5 Sept. 2010**

Yuichiro Tsuchiya, Danielle Vidaurre, Shigeo Toh, Atsushi Hanada, Eiji Nambara, Yuji Kamiya, Shinjiro Yamaguchi, Peter McCourt

▸We discovered that strigolactones which stimulates germination of Striga, also stimulates germination of *Arabidopsis* in the same way that light does. *Striga* is parasitic plant which is causing great damage to crops.

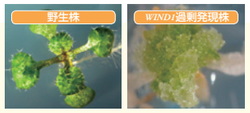
35 Calmodulin-Dependent Activation of MAP Kinase for ROS Homeostasis in *Arabidopsis*

Molecular Cell [vol.41, no.6, pp.649-660] **18 Mar. 2011**

Fuminori Takahashi, Tsuyoshi Mizoguchi, Riichiro Yoshida, Kazuya Ichimura, Kazuo Shinozaki

▸We revealed that the protein kinase MAPK (Mitogen-activated protein kinase) is deeply involved in the signaling of production of reactive oxygen species that occurs in plant response to severe environmental conditions such as disease caused by insects or pathogen, drought, or salinity.

36 The AP2/ERF Transcription Factor WIND1 Controls Cell Dedifferentiation in *Arabidopsis*



❖A plant that over-expresses *WIND1* forms callus.

Current Biology [vol.21 no.6, pp.508–514] **22 Mar. 2011**

Akira Iwase, Nobutaka Mitsuda, Tomotsugu Koyama, Keiichiro Hiratsu, Mikiko Kojima, Takashi Arai, Yasunori Inoue, Motoaki Seki, Hitoshi Sakakibara, Keiko Sugimoto, Masaru Ohme-Takagi

▸We discovered WIND1, a switch protein functions for callus (de-differentiated cellular mass) formation in wounded plants. This is the first key to understanding the long-known phenomenon that plants promote de-differentiation at the molecular level in response to wound stress.

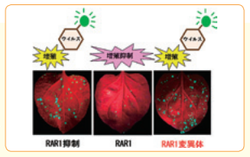
37 Analysis of Cytokinin Mutants and Regulation of Cytokinin Metabolic Genes Reveals Important Regulatory Roles of Cytokinins in Drought, Salt and Abscisic Acid Responses, and Abscisic Acid Biosynthesis

The Plant Cell [vol.23 no.6, pp.2169-2183] **June 2011**

Rie Nishiyama, Yasuko Watanabe, Yasunari Fujita, Dung Tien Le, Mikiko Kojima, Tomás Werner, Radomira Vankova, Kazuko Yamaguchi-Shinozaki, Kazuo Shinozaki, Tatsuo Kakimoto, Hitoshi Sakakibara, Thomas Schmülling, Lam-Son Phan Tran

▸We discovered the mechanism by which interaction between cytokinins (CKs) and abscisic acid (ABA) regulates plant response to drought and salt stress. Development of novel breeding methods are expected.

38 Structural Basis for Assembly of Hsp90-Sgt1-CHORD Protein Complexes: Implications for Chaperoning of NLR Innate Immunity Receptors



❖RAR1 transgenic proteins which cannot bind to SGT1 cannot suppress the spread of the pathogen (virus).

Molecular Cell [vol.39, no.2, pp.269–281] **30 July 2010**

Minghao Zhang, Yasuhiro Kadota, Chrisostomos Prodromou, Ken Shirasu, Laurence H. Pearl

▸We determined the structure of a protein complex (constituted of three proteins, RAR1, SGT1 and HSP90) that is present in both animals and plants. This complex regulates immune sensing. From the structure, we revealed the mechanism by which RAR1 promotes formation of the complex, enhances the function, and thus prevents the invasion of the tobacco mosaic virus.

39 Phosphatidylinositol monophosphate-binding interface in the oomycete RXLR effector AVR3a is required for its stability in host cells to modulate plant immunity

Proc Natl Acad Sci USA [vol.108 no.35, pp.14682-14687] **30 Aug. 2011**

Takashi Yaeno, Hua Li, Angela Chaparro-Garcia, Sebastian Schornack, Seizo Koshiba, Satoru Watanabe, Takanori Kigawa, Sophien Kamoun, Ken Shirasu

▸For the first time we determined the 3D structure of AVR3a, a plant immune-repressing protein. Phytophthora infestans secretes AVR3a, which causes disease in plants. The study revealed a well-conserved lipid binding region, which is required to repress the immune system.

40 The main auxin biosynthesis pathway in *Arabidopsis*

Proc Natl Acad Sci USA [vol. 108 no. 45, pp.18512-18517] **8 Nov. 2011**

Kiyoshi Mashiguchi, Keita Tanaka, Tatsuya Sakai, Satoko Sugawara, Hiroshi Kawaide, Masahiro Natsume, Atsushi Hanada, Takashi Yaeno, Ken Shirasu, Hong Yao, Paula McSteen, Yunde Zhao, Ken-ichiro Hayashi, Yuji Kamiya, Hiroyuki Kasahara

▸From the high-resolution mass analysis of intermediates of IAA biosynthesis, which is the key to elucidate the biosynthesis pathway of auxin in *Arabidopisis*, we revealed that plants synthesize IAA by TAA1 and YUCCA catalyzers from the amino acid tryptophan.

41 The *Arabidopsis* Nitrate Transporter NRT2.4 Plays a Double Role in Roots and Shoots of Nitrogen-Starved Plants

The Plant Cell [vol.24 no.1, pp.245-258] **Jan. 2012**

Takatoshi Kiba, Ana-Belen Feria-Bourrellier, Florence Lafouge, Lina Lezhneva, Stéphanie Boutet-Mercey, Mathilde Orsel, Virginie Bréhaut, Anthony Miller, Françoise Daniel-Vedele, Hitoshi Sakakibara, Anne Krapp

▸We discovered that NRT2.4, an *Arabidopsis* nitrogen transporter, has a role in nitrogen uptake under conditions of nitrogen starvation. This may contribute to development of crops adapted to low input, i.e., sustainable agriculture with small environmental impact.

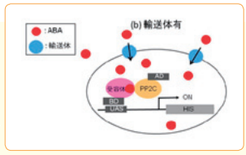
42 Natural variation in a polyamine transporter determines paraquat tolerance in *Arabidopsis*

Proc Natl Acad Sci USA [vol.109 no.16, pp.6343-6347] **17 Apr. 2012**

Miki Fujita, Yasunari Fujita, Satoshi Iuchi, Kohji Yamada, Yuriko Kobayashi, Kaoru Urano, Masatomo Kobayashi, Kazuko Yamaguchi-Shinozaki, Kazuo Shinozaki

▸We discovered that RMV1 protein is the transporter of the bioactive substance polyamines, which are essential for the growth and survival of organisms. Artificial control of the concentration of cellular polyamines is expected to improve stress tolerance or crop yield.

43 Identification of an abscisic acid transporter by functional screening using the receptor complex as a sensor



❖Identification of the importer using yeast two-hybrid assay

Proc Natl Acad Sci USA [vol.109 no.24, pp.9653-9658] **12 June 2012**

Yuri Kanno, Atsushi Hanada, Yasutaka Chiba, Takanari Ichikawa, Miki Nakazawa, Minami Matsui, Tomokazu Koshiba, Yuji Kamiya, Mitsunori Seo

▸The receptor of abscisic acid (ABA), a necessary plant hormone to close stomata, makes a complex with a specific protein when the receptor recognizes ABA. By focusing on this interaction, we discovered that nutrient (nitrate) transporter protein NRT1.2 also functions as an ABA importer.

Principal Investigators from the Plant Science Center

Name	Affiliation	Position
Belay T. AYELE	Department of Plant Science, University of Manitoba, Canada	Assistant Professor
Ivan GALIS	Institute of Plant Science and Resources, Okayama University	Professor
Doug VAN HOEWYK	Department of Biology, Coastal Carolina University, USA	Assistant Professor
Marco TRUJILLO	Independent Junior Research Group / Ubiquitination in Immunity, Leibniz Institute of Plant Biochemistry, Germany	Independent Junior Research Group Leader
Rungaroon WADITEE-SIRISATTHA	Department of Microbiology, Faculty of Science, Chulalongkorn University, Thailand	Lecturer
Koh AOKI	Graduate School of Life and Environmental Sciences, Osaka Prefecture University	Professor
Masashi ASAHINA	Department of Biosciences, Teikyo University	Assistant Professor
Takanari ICHIKAWA	Technology Licensing, and DNA Sequencing Sections, Okinawa Institute of Science and Technology Graduate University	Senior Manager and Section Leader of Business Development
Kazuya ICHIMURA	Faculty of Agriculture, Kagawa University	Associate professor
Hiroki INOUE	The University of Tokyo Forests, Graduate School of Agricultural and Life Sciences, The University of Tokyo	Research Associate
Mikihisa UMEHARA	Department of Applied Biosciences, Undergraduate School of Life Sciences, Toyo University	Associate Professor
Akira OIKAWA	Faculty of Agriculture, Yamagata University	Associate Professor
Naoko OHKAMA-OHTSU	Department of Science of Biological Production, Graduate School of Agriculture, Tokyo University of Agriculture and Technology	Assistant Professor
Kiyoshi OHYAMA	Department of Chemistry and Materials Science, Graduate School of Science and Engineering, Tokyo Institute of Technology	Assistant Professor
Makoto KIMURA	Department of Biological Mechanisms & Functions, Graduate School of Bioagricultural Sciences, Nagoya University	Associate Professor
Hiroaki KUSANO	Department of Biological Science and Technology, Tokyo University of Science	Assistant Professor
Tetsuo KUSHIRO	Department of Agricultural Chemistry, School of Agriculture, Meiji University	Associate Professor
Tetsuya KURATA	Plant Global Education Project, Graduate School of Biological Sciences, Nara Institute of Science and Technology	Associate Professor
Mareshige KOJOMA	Faculty of Pharmaceutical Sciences, Health Sciences University of Hokkaido	Associate Professor
Soichi KOJIMA	Department of Applied Plant Science, Graduate School of Agricultural Science, Tohoku University	Assistant Professor
Yutaka KODAMA	Center for Bioscience Research and Education, Utsunomiya University	Assistant Professor
Koichi KOBAYASHI	Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo	Assistant Professor
Youichi KONDOU	Department of Applied Material and Life Science, Faculty of Engineering, Kanto Gakuin University	Assistant professor
Tatsuya SAKAI	Graduate School of Science and Technology, Niigata University	Associate Professor
Yukihisa SHIMADA	Kihara Institute for Biological Science, Yokohama City University	Professor
Mitsunori SEO	Dormancy and Adaptation Research Unit, RIKEN Plant Science Center	Unit Leader
Hikaru SEKI	Department of Biotechnology, Graduate School of Engineering, Osaka University	Associate Professor

Name	Affiliation	Position
Kazuo SOENO	National Agricultural Reseach Center for Western Region, National Agriculture and Food Research Organization	Senior Researcher
Nobutaka SOMEYA	Hokkaido Agricultural Research Center, National Agriculture and Food Research Organization	Senior Researcher
Tomoyuki TAKASE	Department of Life Science, Faculty of Science, Gakushuin University	Assistant Professor
Hideki TAKAHASHI	Department of Biochemistry and Molecular Biology, Michigan State University	Assistant Professor
Kiyoshi TATEMATSU	Laboratoy of Plant Organ Development, National Institute for Basic Biology	Assistant Professor
Taku DEMURA	Graduate School of Biological Sciences, Nara Institute of Science and Technology	Professor
Makoto TOKUDA	Department of Applied Biological Sciences, Faculty of Agriculture, Saga University	Associate Professor
Hirofumi NAKAGAMI	Plant Proteomics Research Unit, RIKEN Plant Science Center	Unit Leader
Noriko NAGATA	Department of Chemical Biological Sciences, Faculty of Science, Japan Women's University	Associate Professor
Norihito NAKAMICHI	Institute for Advanced Research, Nagoya University	Assistant Professor
Eiji NAMBARA	Department of Cell & Systems Biology, University of Toronto, Canada	Assistant Professor
Kanae NIINUMA	Department of Life Science and Technology, Faculty of Engineering, Hokkai-Gakuen University	Associate Professor
Takumi NISHIUCHI	Advanced Science Research Center, Kanazawa University	Associate Professor
Nobuyuki NISHIKUBO	Forest Technology Laboratories, Research and Development Division, Oji Paper Co., Ltd.	Senior Researcher
Yoshiteru NOUTOSHI	Research Core for Interdisciplinary Sciences, Okayama University	Assistant Professor
Takahito NOMURA	Weed Science Center, Utsunomiya University	Associate Professor
Kousuke HANADA	Frontier Research Academy for Young Researchers, Kyushu Institute of Technology	Associate Professor
Hiroshi HAMAMOTO	Faculty of Bioscience and Applied Chemistry, Hosei University	Professor
Akiko HARADA	Department of Biology, Osaka Medical College	Junior Associate Professor
Gorou HORIGUCHI	Department of Life Science, College of Science, Rikkyo University	Associate Professor
Ken MATSUOKA	Faculty of Agriculture, Kyushu University	Professor
Fumio MATSUDA	Graduate School of Information Science and Technology, Osaka University	Associate professor
Akiko MARUYAMA-NAKASHITA	Bioscience & Biotechnology, Graduate School of Bioresource and Bioenvironmental Sciences, Kyushu University	Associate Professor
Toshiya MURANAKA	Department of Biotechnology, Graduate School of Engineering, Osaka University	Professor
Masatoshi YAMAGUCHI	Institute for Environmental Science and Technology, Saitama University	Associate Professor
Shinjiro YAMAGUCHI	Graduate School of Life Sciences, Tohoku University	Professor
Yoshiharu Y. YAMAMOTO	Faculty of Applied Biological Sciences, Gifu University	Associate Professor
Kohki YOSHIMOTO	The Jean-Pierre Institute at the INRA Versailles-Grignon Center, France	INRA Researcher
Naoko YOSHIMOTO	Graduate School of Pharmaceutical Sciences, Chiba University	Assistant Professor
Arata YONEDA	Graduate School of Biological Sciences, Nara Institute of Science and Technology	Assistant Professor

Awards

Name	Position	Group / Laboratory	Team	Name of award	Presentation title, research subject and subject of paper etc.	Date of award
2001						
Hideharu SETO	Research Scientist	Functional Control Research Group	Laboratory for Growth Regulation	The JSCRP Award	Synthesis of Molecular Probes of Plant Hormones Based on Fine and Precision Synthetic Chemistry and Their Application	Oct.
2002						
Shigeo YOSHIDA	Group Director	Functional Control Research Group		The JSPCMB Award for Technical Advance	Development of mutant induction by heavy ion beam and its applicatio	Jul.
2003						
Nobutaka SOYEYA	Research Scientist	Environmental Plant Research Group	Laboratory for Adaptation and Resistance	Award for Paper of excellence, The Phytopathological Society of Japan	Synergistic Antifungal Activity of Chitinolytic Enzymes and Prodigiosin Produced by Biocontrol Bacterium *Serratia marcescens* strain B2 against the Gray Mold Pathogen, *Botrytis cinerea*	Mar.
Yuji KAMIYA	Group Director	Growth Physiology Research Group		Corresponding Member (conferred by The American Society of Plant Biologists)	Research activities to date	Jul.
Yukihisa SHIMADA	Research Scientist	Functional Control Research Group	Laboratory for Growth Regulation	The JSCRP Award for the Encouragement of Young Scientists	Molecular Biological Study of Brassinosteroid-related Genes	Oct.
Tatsuo SUGIYAMA	Director			L'Ordre des Palmes Académiques-Officier	Research and other activities to date. Contribution to education and research activities between Japan and France	Nov.
2004						
Hitoshi SAKAKIBARA	Team Leader	Metabolic Function Research Group	Laboratory for Communication Mechanisms	Japanese Society of Plant Physiologists Young Investigator Award	Research on nitrogen nutrient information transfer mechanisms in higher plants	28 Mar.
Isamu YAMAGUCHI	Group Director	Environmental Plant Research Group		Japan Prize of Agricultural Science, Yomiuri Agriculture Prize	Research on the pathological structure and metabolism of environmentally harmonized plant disease inhibitors	5 Apr.
Tomoyuki YAMAYA Keiki ISHIYAMA Naoya HIROSE	Group Director, Research Scientist	Metabolic Function Research Group		The JSPCMB Excellent Paper Award	Organization and Structure of Intracellular Localization of the Enzyme Protein in Rice Plants	9 Aug.
Yuji KAMIYA	Group Director	Growth Physiology Research Group	Laboratory for Cellular Growth and Development	IPGSA Distinguished Research Award	Research on gibberellin biosynthesis and its contribution to the internationalization of research in that field	21 Sep.
2005						
Hideki TAKAHASHI	Team Leader	Metabolic Function Research Group	Laboratory for Metabolic Compartmentation	Japanese Society of Plant Physiologists Young Investigator Award	Research on the physiological functions and control of sulphate ion transport systems	25 Mar.
Shigeo YOSHIDA	Coordinator			Japan Prize of Agricultural Science, Yomiuri Agriculture Prize	Research on the development of a technological platform for plant growth adjustment	5 Apr.
Yukihisa SHIMADA	Senior Research Scientist	Metabolomics Research Group	Integrated Genomics Research Team	Emerging Research Fronts in Plant & Animal Science	Paper : Brassinolide induces IAA5, IAA19, and DR5, a synthetic auxin response element in *arabidopsis*, implying a cross talk point of brassinosteroid and auxin signaling	1 Jun.
Masami Yokota HIRAI	Unit Leader	Metabolomics Research Group	Metabolic Systems Research Unit	The JSPCMB Award for Young Scientists	Postgenomics approaches for the elucidation of the adaptive responses to sulfur deficiency	5 Aug.
Taku DEMURA	Team Leader	Plant Productivity Systems Research Group	Morphoregulation Research Team	BSJ Award for Young Scientists	Analysis of molecular mechanism controlling differentiation of xylem cells	22 Sep.
Takahito NOMURA	Special Postdoctoral Researcher	Growth Regulation Research Group	Cellular Growth and Development Research Team	The JSCRP Award for the Encouragement of Young Scientists	Research on biosynthesis of brassinosteroids, and the isolation and functions of receptor genes	1 Nov.
2006						
Eiji NAMBARA	Team Leader	Growth Regulation Research Group	Dormancy and Adaptation Research Team	Japanese Society of Plant Physiologists Young Investigator Award	Genetic analysis of abscisic acid action in seeds	20 Mar.
Kazuo SHINOZAKI	Director			The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology (Research Category)	Research on abiotic stress responses and plant genomic functions in acquired tolerance	18 Apr.
Madoka AYANO	Research Associate	Metabolomics Research Group	Integrated Genomics Research Team	Best Paper Award (Journal of Plant Research)	Developmental morphology of the Asian one-leaf plant, *Monophyllaea glabra* (Gesneriaceae) with emphasis on inflorescence morphology	15 Sep.

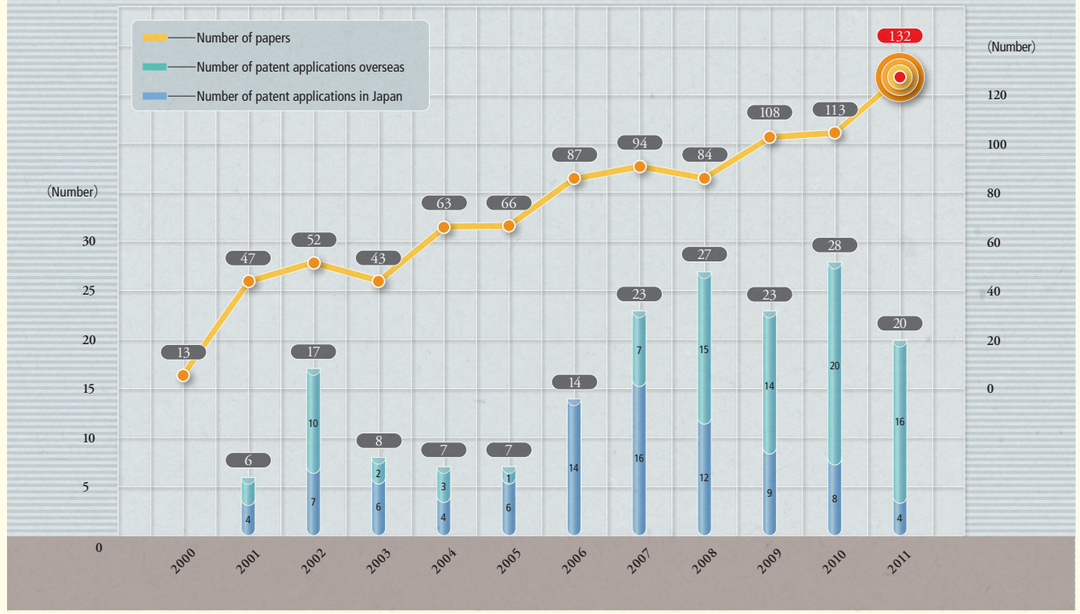
Awards

Name	Position	Group / Laboratory	Team	Name of award	Presentation title, research subject and subject of paper etc.	Date of award
2007						
Akiko MARUYAMA-NAKASHITA	Research Scientist	Metabolic Function Research Group	Plant Nutrition and Basal Metabolism Research Team	The JSPCMB Award for Young Scientists	Elucidation of sulfur and related metabolic control mechanisms in plants	8 Aug.
Yasuhiro KADOTA	Special Postdoctoral Researcher	Plant Immunity Research Group	Plant Immunity Research Team	BSJ Award for Junior Young Scientists	The role and cell cycle dependence of Ca^{2+} signal transduction system in induced defense reaction mechanisms of BY-2 cultured tobacco cells against blight stress and reactive oxygen stress	8 Sep.
Sigeo YOSHIDA	Coordinator			Local Commendation for Invention (Kanto block)	Constructing chimeric plants with heavy ion beams	9 Nov.
2008						
Kiminori TOYOOKA Mayuko SATO	Research Scientist Technical Scientist	Gene Discovery Research Group	R&D Programs for PSC	EMBO Journal Cover Contest higher-ranking winner	"Plant neuron"- A scanning electron microscopy image showing trichomes on a leaf of *Verbascum thapsus* (Great Mullein).	14 Feb.
Tetsuya SAKURAI Motoaki SEKI Kazuo SHINOZAKI	Unit Leader Team Leader Director		Integrated Genome Informatics Research Unit, Plant Genomic Network Research Team	CIAT-Outstanding Research Publication Award	Sequencing analysis of 20,000 full-length cDNA clones from cassava reveals lineage specific expansions in gene families related to stress response	18 Apr.
Kiminori TOYOOKA	Research Scientist	Gene Discovery Research Group	R&D Programs for PSC	Excellent Paper Award of the Society for Biotechnology, Japan	Development of Series of Gateway Binary Vectors, pGWBs, for Realizing Efficient Construction of Fusion Genes for Plant Transformation	27 Aug.
Misao ITOUGA	Research Scientist	Plant Productivity Systems Research Group	Biodynamics Research Team	Awards for young bryologists	Research on technology for using moss to reduce impacts on the aquatic environment	30 Aug.
Keiko YONEKURA-SAKAKIBARA	Research Scientist	Metabolic Function Research Group	Metabolic Function Research Team	The JSPCMB Award for Young Scientists	Profiling of flavonoid regulatory mechanisms in higher plants	1 Sep.
Hiroyuki KASAHARA	Senior Research Scientist	Growth Regulation Research Group	Growth Regulation Research Team	The JSCRP Award for the Encouragement of Young Scientists	Biosynthesis of hormones through the methylerythritol phosphate (MEP) pathway	29 Oct.
2009						
Kiminori TOYOOKA Mayuko SATO Mayumi WAKAZAKI	Research Scientist Technical Scientist Contract Technical Assistant	Gene Discovery Research Group	R&D Programs for PSC	EMBO Journal Cover Contest higher-ranking winner	Mushroom-shaped oil glands on the surface of a Basil sepal	11 Feb.
Kazuo SHINOZAKI	Director			Japanese Society of Plant Physiologists Award	Elucidation of the genetic regulatory network involved in abiotic stress mechanisms and acquired resistance	22 Mar.
Tatsuya SAKAI	Team Leader	Gene Discovery Research Group	Genetic Regulatory Systems Research Team	Japanese Society of Plant Physiologists Young Investigator Award	Molecular genetic analysis of growth pattern control mechanisms in plant responses to light	22 Mar.
Keiko SAKAKIBARA	Research Scientist	Metabolic Function Research Group	Metabolic Function Research Team	JSPP Plant and Cell Physiology Award for the Paper of Excellence	Engineering of the Rose Flavonoid Biosynthetic Pathway Successfully Generated Blue-Hued Flowers Accumulating Delphinidin	22 Mar.
Shinjiro YAMAGUCHI	Team Leader	Growth Regulation Research Group	Cellular Growth and Development Research Team	Japan Society for Bioscience, Biotechnology, and Agrochemistry Award for the Encouragement of Young Scientists	Research on the biosynthesis and physiological functions of terpenoid plant hormones	27 Mar.
Hitoshi SAKAKIBARA	Group Director	Plant Productivity Systems Research Group		The Olchemim Award	Biochemistry and molecular biology of phytohormone cytokinin	11 Jul.
Kazuo SHINOZAKI Kazuko YAMAGUCHI-SHINOZAKI	Director Visiting Scientist (Gene Discovery Research Group)			Top five Plant Cell manuscripts	Two transcription factors, DREB1 and DREB2, with an EREBP/AP2 DNA binding domain separate two cellular signal transduction pathways in drought- and low-temperature-responsive gene expression, respectively, in *Arabidopsis*	21 Jul.
Shinjiro YAMAGUCHI	Team Leader	Growth Regulation Research Group	Cellular Growth and Development Research Team	The JSCRP Award	Bioorganic chemical research on terpenoid plant hormones using mutants	29 Oct.
Kiminori TOYOOKA Mayumi WAKAZAKI	Research Scientist Contract Technical Assistant	Gene Discovery Research Group	R&D Programs for PSC	Olympus BioScapes International Digital Imaging Competition, Honorable Mention	Epidermal layer cells of *Lotus japonicus* dry seed	6 Dec.
Ayako KAWAMURA	Technical Staff	Gene Discovery Research Group	Cell Function Research Unit	Jury's Special Award, Leica mycrosystems photo contest	Trichome	9 Dec.

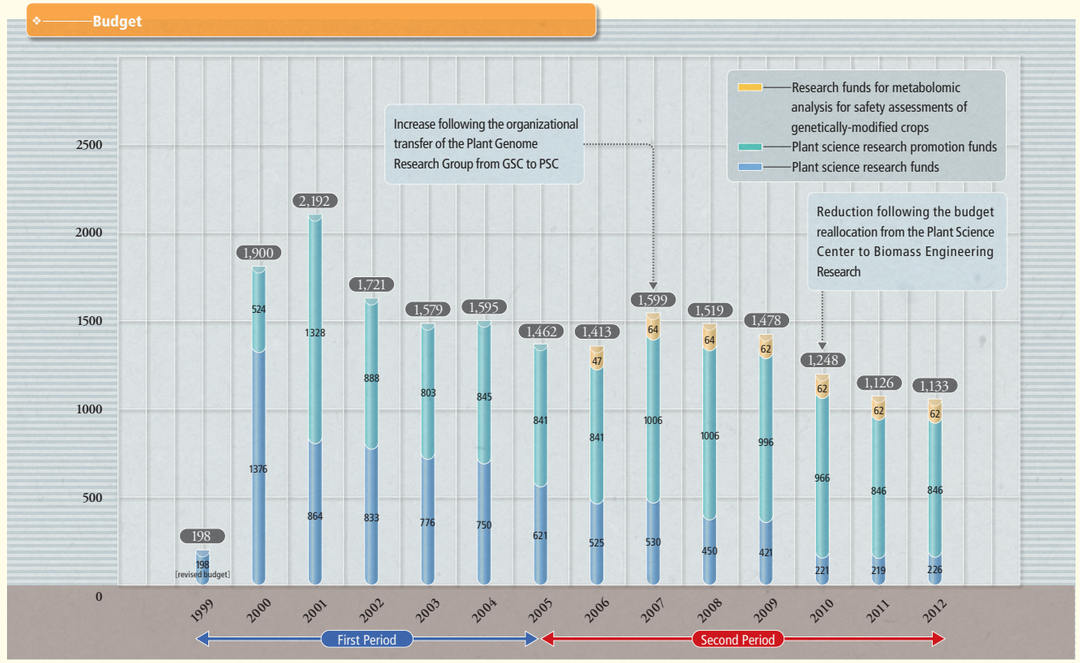
Name	Position	Group / Laboratory	Team	Name of award	Presentation title, research subject and subject of paper etc.	Date of award
2010						
Yukihisa SHIMADA	Team Leader	Metabolomics Research Group	Integrated Genomics Research Team	New Hot Paper in Plant & Animal Science	The AtGenExpress hormone- and chemical-treatment data set: Experimental design, data evaluation, model data analysis, and data access	4 Jan.
Hitoshi SAKAKIBARA	Group Director	Plant Productivity Systems Research Group		JSPS Prize	Elucidation of cytokinin synthesis mechanism and discovery of a new function in particle control	1 Mar.
Keiko SUGIMOTO-SHIRASU	Unit Leader	Gene Discovery Research Group	Cell Function Research Unit	Japanese Society of Plant Physiologists Young Investigator Award	Analysis of the developmental genetics of plant endoreduplication and cell size control	19 Mar.
Yuji KAMIYA	Group Director	Growth Regulation Research Group		Japan Prize of Agricultural Science, Yomiuri Agriculture Prize	Research on mechanisms of actions in gibberellin biosynthesis and plant growth regulators	5 Apr.
Kazuki SAITO	Deputy Director			The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology (Research Category)	Research on functional genomics for plants based on metabolomics	13 Apr.
Hitoshi SAKAKIBARA	Group Director	Plant Productivity Systems Research Group		Kihara Memorial Foundation Special Award	Elucidation of cytokinin biosynthesis pathways and their use in breeding	14 May
Mikihisa UMEHARA	Research Scientist	Cellular Growth and Development Research Team		The JSPCMB Award for Young Scientists	Research on strigolactones, a hormone controlling branching in plants	2 Sep.
Yoshiyuki OGATA	Research Scientist	Advanced NMR Metabomics Research Team		The JSPCMB Award for Young Scientists	Development of methods for analyzing gene coexpression for inferring comprehensive functions of plant genes and construction of an analysis database	2 Sep.
Hiroshi MAGOME	Research Scientist	Cellular Growth and Development Research Team		The JSCRP Award for the Encouragement of Young Scientists	Molecular biological research on enzymes controlling the gibberellin activation	1 Nov.
Eiji NAMBARA	Senior Visiting Scientist	Growth Regulation Research Group		The JSCRP Award	Research on molecular genetics involved in abscisic acid metabolism and information transfer	1 Nov.
2011						
Ken SHIRASU	Group Director	Plant Immunity Research Group		Kihara Memorial Foundation Academic Award	Elucidation of molecular mechanism of the immune system in plants	20 May
Kazuki SAITO	Deputy Director			The JSPCMB Award for Distinguished Research	Integrated omics study based on plant metabolomics and its development	6 Sep.
Takashi ISHIDA	Special Postdoctoral Researcher	Cell Function Research Unit		BSJ Award for Junior Young Scientists	Research on molecular mechanisms responsible for cell morphogenesis	18 Sep.
Jun KIKUCHI Yasuhiro DATE	Team Leader Postdoctoral Researcher	Advanced NMR Metabomics Research Team		Excellent Paper Award of the Society for Biotechnology, Japan	New monitoring approach for metabolic dynamics in microbial ecosystems using stable-isotope-labeling technologies	26 Sep.
2012						
Shinjiro YAMAGUCHI	Team Leader	Cellular Growth and Development Research Team		Research Front Award, Thomson Reuters	New developments in strigloactone research based on the discovery of plant hormone functions	21 Feb.
Kei HASHIMOTO	Technical Scientist	R&D Programs for PSC		EMBO Journal Cover Contest higher-ranking winner	Love Dust - Pheromone transfer particles called "love dust" produced in the hindwing of a male butterfly (*Tirumala formosa*)	12 Mar.
Hitoshi SAKAKIBARA Misao ITOUGA Seiji NAKATSUKA	Group Director, Senior Research Scientist, Visiting Scientist	Plant Productivity Systems Research Group		Japan Mining Industry Association Award	Moss as a material for recovering heavy metals	30 Mar.
Kazuo SHINOZAKI	Director			Hottest Researchers, Thomson Reuters	"With 11 of his papers selected as "hot papers" Nominated as the world's 5th "Hottest Researcher"	12 Apr.
Miyako KUSANO	Senior Research Scientist	Metabolomic Function Research Group		The JSPCMB Award for Young Scientists	Elucidation of plant metabolic networks using metabolomics	4 Aug.
Satoko YOSHIDA	Senior Research Scientist	Plant Immunity Research Group		BSJ Award for Young Scientists	Establishment of an analysis platform for the parasitic plant striga and identification of its parasitic structure	16 Sep.
Kensuke KAWADE	Special Postdoctoral Researcher	Metabolic Systems Research Team		BSJ Award for Junior Young Scientists	Leaf size control that develops in multicellular organisms	16 Sep.
Hiroo FUKUDA	Senior Visiting Scientist			The Medal with Purple Ribbon	Achievements in plant physiology research	13 Nov.
Hiroyuki KASAHARA	Senior Research Scientist	Growth Regulation Research Group		JSPS Prize	Elucidation of the major pathways of auxin biosynthesis in plants	17 Dec.

Factual Data of the Plant Science Center

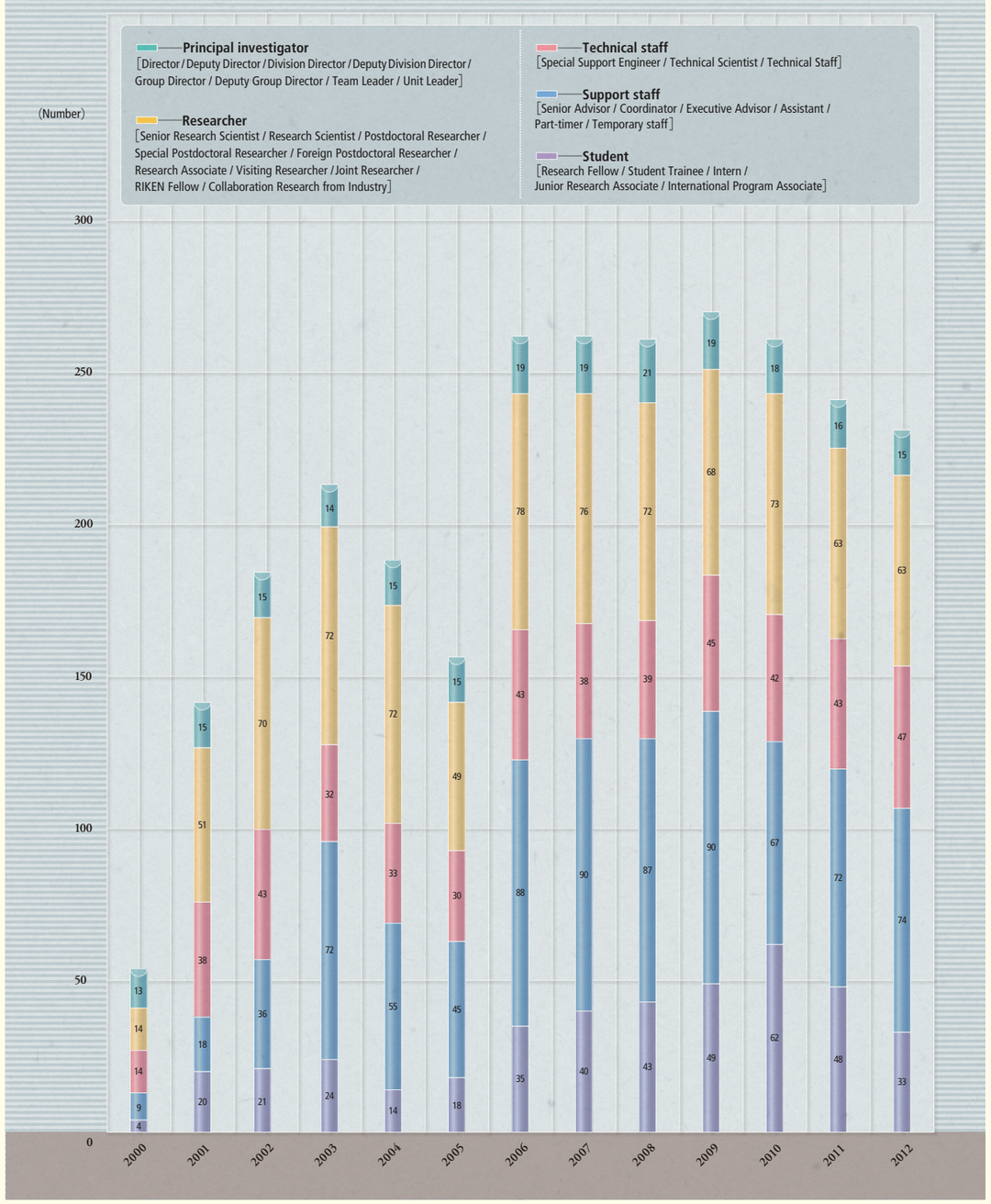
Number of papers / Number of patent applications in Japan and Overseas



Budget



Number of employees (as of March 31, 2012)



PSC Publications 2000–2012

001 Estevez J, Cantero A, Romero C, Kawaide H, Jimenez L, Kuzuyama T, Seto H, Kamiya Y, Leon P, "Analysis of the expression of *CLA1*, a gene that encodes the 1-deoxyxylulose 5-phosphate synthase of the 2-*C*-methyl-D-erythritol-4-phosphate pathway in Arabidopsis" *Plant Physiology* **124** 95-103 (2000)

002 Fukazawa J, Sakai T, Ishida S, Yamaguchi I, Kamiya Y, Takahashi Y, "Repression of Shoot Growth, a bZIP transcriptional activator, regulates cell elongation by controlling the level of gibberellins" *The Plant Cell* **12** 901-915 (2000)

003 Fukuda H, "Programmed cell death of tracheary elements as a paradigm in plants" *Plant Molecular Biology* **44** 245-253 (2000)

004 Ghassemian M, Nambara E, Cutler S, Kawaide H, Kamiya Y, McCourt P, "Regulation of abscisic acid signaling by the ethylene response pathway in Arabidopsis" *The Plant Cell* **12** 1117-1126 (2000)

005 Jones R, Harberd N, Kamiya Y, "Gibberellins 2000" *Trends in Plant Science* **5** 320-321 (2000)

006 Min X, Okada K, Brockmann B, Koshiba T, Kamiya Y, "Molecular cloning and expression patterns of three putative functional aldehyde oxidase genes and isolation of two aldehyde oxidase pseudogenes in tomato" *Biochimica et Biophysica Acta* **1493** 337-341 (2000)

007 Nakashima J, Takabe K, Fujita M, Fukuda H, "Autolysis during in vitro tracheary element differentiation: Formation and location of the perforation" *Plant Cell Physiology* **41** 1267-1271 (2000)

008 Nambara E, Hayama R, Tsuchiya Y, Nishimura M, Kawaide H, Kamiya Y, Naitou S, "The role of *ABI3* and *FUS3* loci in *Arabidopsis thaliana* on phase transition from late embryo development to germination" *Developmental Biology* **220** 412-423 (2000)

009 Sang S, Lao A, Chen Z, Uzawa J, Fujimoto Y, "Three new triterpenoid saponins from the seeds of *Vaccaria segetalis*" *Jounal of Asian Natural Products Research* **2** 187-193 (2000)

010 Sang S, Lao A, Leng Y, Gu Z, Chen Z, Uzawa J, Fujimoto Y, "Segetoside F a new triterpenoid saponin with inhibition of luteal cell from the seeds of *Vaccaria segetalis*" *Tetrahedron Letters* **41** 9205-9207 (2000)

011 Seo M, Koiwai H, Akaba S, Komano T, Oritani T, Kamiya Y, Koshiba T, "Abscisic aldehyde oxidase in leaves of *Arabidopsis thaliana*" *The Plant Journal* **23** 481-488 (2000)

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013 Sugiyama M, Ito J, Aoyagi S, Fukuda H, "Endonucleases" *Plant Molecular Biology* **44** 387-397 (2000)

014 Arai Y, Nakashita H, Doi Y, Yamaguchi I, "Plastid targeting of polyhydroxybutyrate biosynthetic pathway in tobacco" *Plant Biotechnology* **18** 289-293 (2001)

015 Asami T, Mizutani M, Fujioka S, Goda H, Min Y, Shimada Y, Nakano T, Takatsuto S, Matsuyama T, Nagata N, Sakata K, Yoshida S, "Selective interaction of triazole derivatives with DWF4, a cytochrome P450 monooxygenase of the brassinosteroid biosynthetic pathway, correlates with brassinosteroid deficiency *in Planta*" *The Journal of Biological Chemistry* **276** 25687-25691 (2001)

016 Bhaya D, Takahashi A, Grossman A, "Light regulation of type IV pilus-dependent motility by chemosensor-like elements in *Synechocystis* PCC6803" *Proceedings of the National Academy of Sciences of the United States of America* **98** 7540-7545 (2001)

017 Bhaya D, Takahashi A, Shahi P, Grossman A, "Novel motility mutants of *Synechocystis* strain PCC 6803 generated by in vitro transposon mutagenesis" *Journal of Bacteriology* **183** 6140-6143 (2001)

018 Brockmann B, Smith M, Zarainsky A, Harrison K, Okada K, Kamiya Y, "Subcellular localization and targeting of glucocorticoid receptor protein fusions expressed in transgenic *Arabidopsis thaliana*" *Plant Cell Physiology* **42** 942-951 (2001)

019 Eckardt N, Araki T, Benning C, Cubas P, Goodrich J, Jacobsen S, Masson P, Nambara E, Simon R, Somerville S, Wasteneys G, "Arabidopsis research 2001" *The Plant Cell* **13** 1973-1982 (2001)

020 Eizuka T, Sato T, Chida T, Yamaguchi I, "Simple method for monitoring the sensitivity of *Pyricularia oryzae* to fthalide" *Journal of Pesticide Science* **26** 385-389 (2001)

021 Endo S, Demura T, Fukuda H, "Inhibition of proteasome activity by the TED4 protein in extracellular space: A novel mechanism for protection of living cells from injury caused by dying cells" *Plant Cell Physiology* **42** 9-19 (2001)

022 Grossman A, Takahashi H, "Macronutrient utilization by photosynthetic eukaryotes and the fabric of interactions" *Annual Review of Plant Physiology Plant Molecular Biology* **52** 163-210 (2001)

023 Hamamoto H, Hasegawa K, Nakaune R, Lee Y, Akutsu K, Hibi T, "PCR-based detection of sterol demethylation inhibitor-resistant strains of *Penicillium digitatum*" *Pest Management Science* **57** 839-843 (2001)

024 Hamamoto H, Nawata O, Hasegawa K, Nakaune R, Lee Y, Makizumi Y, Akutsu K, Hibi T, "The role of the ABC transporter gene *PMR1* in demethylation inhibitor resistance in *Penicillium digitatum*" *Pesticide Biochemistry and Physiology* **70** 19-26 (2001)

025 Kagawa T, Sakai T, Suetsugu N, Oikawa K, Ishiguro S, Kato T, Tabata S, Okada K, Wada M, "*Arabidopsis* NPL1: A phototropin homolog controlling the chloroplast high-light avoidance response" *Science* **291** 2138-2141 (2001)

026 Kim H, Yamaguchi I, Cho K, "The secondary effects of Pencycuron on the formation of giant protoplasts and the lipid peroxidation of *Rhizoctonia solani* AG4" *The Plant Pathology Journal* **17** 36-39 (2001)

027 Kimura M, Anzai H, Yamaguchi I, "Microbial toxins in plant-pathogen interactions: Biosynthesis, resistance mechanisms, and significance" *The Journal of General and Applied Microbiology* **47** 149-160 (2001)

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030 Motose H, Sugiyama M, Fukuda H, "An arabinogalactan protein(s) is a key component of a fraction that mediates local intercellular communication involved in tracheary element differentiation of zinnia mesophyll cells" *Plant Cell Physiology* **42** 129-137 (2001)

031 Motose H, Sugiyama M, Fukuda H, "Cell-cell interactions during vascular development" *Journal of Plant Research* **114** 473-481 (2001)

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033 Nagatsuka Y, Kasama T, Ohashi Y, Uzawa J, Ono Y, Shimizu K, Hirabayashi Y, "A new phosphoglycerolipid, 'phosphatidylglucose', found in human cord red cells by multi-reactive monoclonal anti-i cold agglutinin, mAb GL-1/GL-2" *FEBS Letters* **497** 141-147 (2001)

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038 Noji M, Takagi Y, Kimura N, Inoue K, Saito M, Horikoshi M, Saito F, Takahashi H, Saito K, "Serine acetyltransferase involved in cysteine biosynthesis from spinach: Molecular cloning, characterization and expression analysis of cDNA encoding a plastidic isoform" *Plant Cell Physiology* **42** 627-634 (2001)

039 Nomura T, Sato T, Bishop G, Kamiya Y, Takatsuto S, Yokota T, "Accumulation of 6-deoxocathasterone and 6-deoxocastasterone in *Arabidopsis*, pea and tomato is suggestive of common rate-limiting steps in brassinosteroid biosynthesis" *Phytochemistry* **57** 171-178 (2001)

040 Obara K, Kuriyama H, Fukuda H, "Direct evidence of active and rapid nuclear degradation triggered by vacuole rupture during programmed cell death in zinnia" *Plant Physiology* **125** 615-626 (2001)

041 Obara M, Kajiura M, Fukuta Y, Yano M, Hayashi M, Yamaya T, Sato T, "Mapping of QTLs associated with cytosolic glutamine synthetase and NADH - glutamate synthase in rice (*Oryza sativa* L.)" *Journal of Experimental Botany* **52** 1209-1217 (2001)

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