rice TODAY

ricetoday.irri.org
International Rice Research Institute
July-September 2017, Vol. 16, No. 3

Cutting-edge science meets rice research

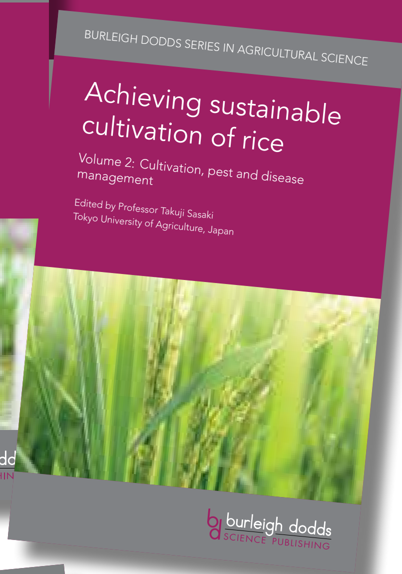
US$5.00 ISSN 1655-5422

BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

NEW RICE BOOKS

COMING SOON!

climate•SMART•publishing
IN AGRICULTURAL SCIENCE



Achieving sustainable cultivation of rice - Volumes 1 & 2

Edited by: Takuji Sasaki, Tokyo University of Agriculture, Japan

KEY FEATURES

- Reviews advances in breeding, exploiting the genetic diversity of rice and enhancing properties such as yield, nutritional value and drought tolerance
- Summarises advances in cultivation practices to close yield gaps and methods of 'climate-smart' cultivation such as SRI
- Reviews the latest research on insect pests, integrated pest and weed management

Rice insect pests and their management

E.A. Heinrichs, Francis E. Nwilene, Michael J. Stout, Buying A. R. Hadi and Thais Freitas

KEY FEATURES

- Covers almost 100 species of the most important insect pests affecting rice cultivation
- Brings together the key research on each pest, including description and biology and effects on rice plants
- Written by a team of leading entomologists with experience of rice pests in Asia, Africa, the United States and Latin America
- Includes over 150 photographs and images

How to order

Available in print and online formats
For more information about these titles please visit our website
www.bdspublishing.com
or email jenny.wheeler@bdspublishing.com
For a FREE rice chapter simply sign up for our e-newsletter via the 'Contact us' page on the website

www.bdspublishing.com

burleigh dodds
SCIENCE PUBLISHING

CONTENTS

rice TODAY Vol. 16, No. 3

About the cover

Rice scientists are responding to challenges like diseases and climate change with the latest research trends and the use of rapidly advancing techniques in molecular breeding, genetics, phenomics, drone technology, and more. Their works bring a wealth of relatable and relevant knowledge that promise to greatly impact the world's rice farmers and consumers.
(Photo by Isagani Serrano, IRRI)

Rice Today is published by the International Rice Research Institute (IRRI) on behalf of the Global Rice Science Partnership (GRiSP).

IRRI is the world's leading international rice research and training center. Based in the Philippines and with offices located in major rice-growing countries, IRRI is an autonomous, nonprofit institution focused on improving the well-being of present and future generations of rice farmers and consumers, particularly those with low incomes, while preserving natural resources. It is one of the 15 nonprofit international research centers that are members of the CGIAR System (www.cgiar.org).

Responsibility for this publication rests with IRRI. Designations used in this publication should not be construed as expressing IRRI policy or opinion on the legal status of any country, territory, city, or area, or its authorities, or the delimitation of its frontiers or boundaries.

Rice Today welcomes comments and suggestions from readers. The opinions expressed by columnists in *Rice Today* do not necessarily reflect the views of IRRI or GRiSP.

Moreover, IRRI or GRiSP does not endorse any advertised product, service, or company, nor any of the claims made by the advertisement in the magazine.

International Rice Research Institute
DAPO Box 7777, Metro Manila, Philippines
Web: ricetoday.irri.org

Rice Today editorial
telephone: (+63-2) 580-5600 or (+63-2) 844-3351 to 53, ext 2725; fax: (+63-2) 580-5699 or (+63-2) 845-0606; email: info_ricetoday@irri.org

editor **Alaric Francis Santiaguel**
Africa editor **Savitri Mohapatra**
Latin America editor **Neil Palmer**
copy editor **Bill Hardy**
designer and production supervisor **Grant Leceta**
photo editor **Isagani Serrano**
printer **CGK formaprint**

Science stories

by Alaric Francis **Santiaguel**

There is a divide between the science community and the world outside that can be linked to a "language barrier." Some scientists, American astrophysicist Neil deGrasse Tyson, for example, have mastered the art of spinning scientific literature of, literally, cosmic proportions into compelling and entertaining narratives:

> In a trillion or so years, anyone alive in our own galaxy may know nothing of other galaxies. Our observable universe will merely comprise a system of nearby, long-lived stars within the Milky Way. And beyond this starry night will lie an endless void—darkness, the face of the deep. *(Astrophysics for People in a Hurry,* W. W. Norton & Company; 1st edition, 2017)

But, from my experience, most scientists struggle with communicating their work to people who are not in their circle of colleagues. One scientist described her predicament as "frustrating." She told me how much she wanted to reach out to a broader audience but she didn't know how. The consequence of this disconnect isn't just a bored or befuddled audience. It is a missed opportunity to show just how important science is to *everyone*. In the words of Dr. Tyson:

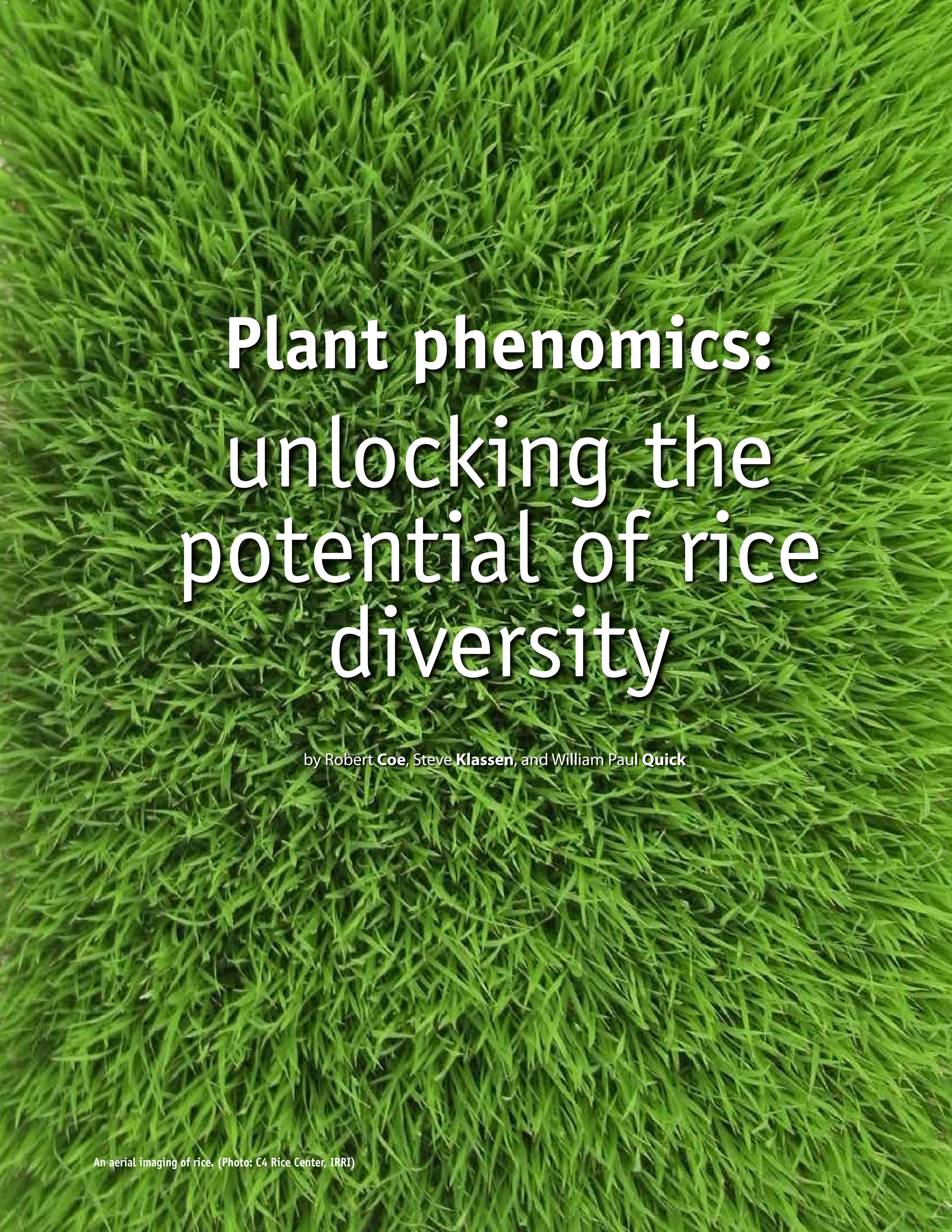
> Once you have an innovation culture, even those who are not scientists or engineers—poets, actors, journalists—they, as communities, embrace the meaning of what it is to be scientifically literate. They embrace the concept of an innovation culture. They vote in ways that promote it. They don't fight science and they don't fight technology. (*Neil deGrasse Tyson: Invest in NASA, Invest in U.S. Economy,* Forbes, 2012)

People cannot embrace science literacy if they think of science as something that happens in an obscure laboratory where stereotypical socially awkward people clumsily bump into each other! The truth is, down the line, the impact of science hits very close to home and thus merits a hearty curiosity. *Rice Today* was created to transform the cold, hard facts of scientific reports into "embraceable" stories.

This issue, in particular, features cutting-edge research predicted to make significant global changes, such as the marriage of drone technology and plant phenomics and starving to death a bacterium that destroys rice rather than killing it with toxic chemicals. We feature six winning research proposals ranging from creating an Uber-like service for rice farmers to revving up chloroplasts, the most important biological machines on Earth.

For a more challenging read, we have a story on CRISPR. This game-changing genome editing tool with unprecedented precision is creating a big buzz in the science world for a good reason. It could help plant scientists develop rice varieties that are more resilient to weeds, pests, flood, salinity, and drought at a rate fast enough to keep up with the changing world.

Yes, science can be interesting stories and we have these, and much more, from cover to cover. ■



Plant phenomics: unlocking the potential of rice diversity

by Robert **Coe**, Steve **Klassen**, and William Paul **Quick**

An aerial imaging of rice. (Photo: C4 Rice Center, IRRI)

A foundation for improving rice production in the future lies in unlocking the diversity found within the International Rice Genebank. In 2014, the full genome sequence of 3,000 varieties was released in order to help unlock the secrets contained within. With access to the rice genetic code, breeders were offered the ability to rewrite it and produce new varieties fit for the future.

Unfortunately, a piece of the puzzle is still missing—scientists do not know what most of the code does. As a rough estimate, more than 70% of the 55,000 genes that make up the genetic code have no known function. What's more, much of the diversity in rice results from the natural rewriting of this code. Altering just a single digit can change the entire function of a gene. To understand what happens when this occurs, scientists must measure the physical manifestation of the genes or phenotype.

Bridging the gap

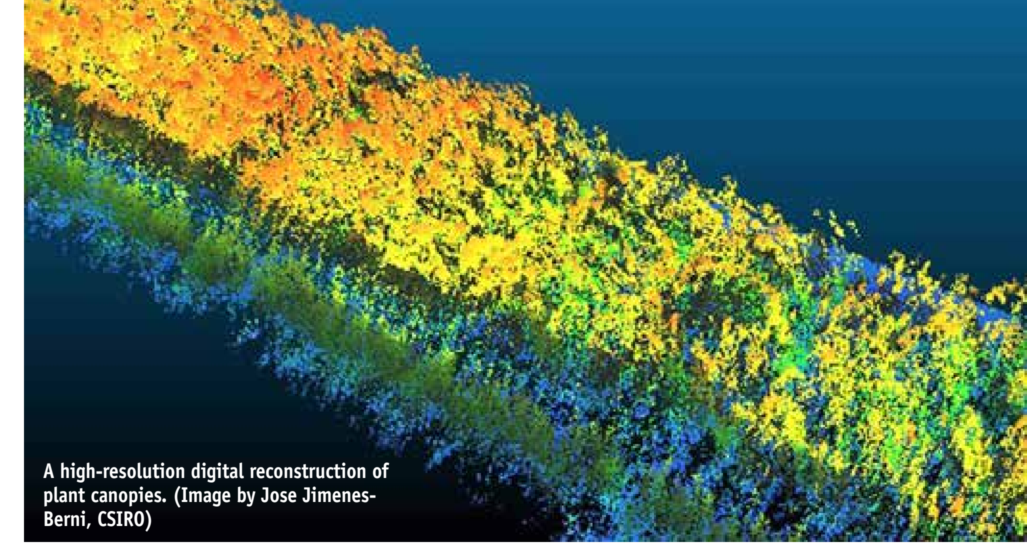
Most breeders will tell you that measuring a phenotype, or phenotyping, is laborious, expensive, and, often, technically challenging. Take for example the measurement of yield for 3,000 rice varieties: a minimum of 1.1 million plants need to be grown and harvested across three separate seasons at one location. Understanding why variation occurred in yield would necessitate the measurement of a plethora of additional characteristics, many far beyond current scientific capabilities. As a result, it is rarely possible to measure phenotypes in detail on very large numbers of plants.

The emerging field of plant phenomics combines the disciplines of biology, engineering, and data analytics to offer a suite of new technologies to overcome what is known as the phenotyping bottleneck. It capitalizes on advances in imaging, sensing, spectroscopy, and robotics to noninvasively study plant growth, performance, and composition. It is exploratory research aimed at finding valuable new ways to phenotype.

Digital agriculture

A cornerstone of phenomics is the ability to make noninvasive measurements of quantifiable plant phenotypes known as traits. A wide array of instruments for sensing and imaging is being tested at the International Rice Research Institute (IRRI) for this purpose. The most familiar of these are the RGB cameras capable of capturing color photographs; these images can be analyzed to obtain information about color, shape, and structure. Operating beyond the physical capabilities of the human eye, thermal-imaging cameras detect near-infrared radiation. More commonly used by firefighters, these cameras can distinguish objects within images based upon differences in their temperature. These cameras allow monitoring of plant responses to changes in the environment, such as the onset of drought.

Various types of spectral imagers are being used to measure the reflectance of light from rice canopies. These have a unique signature related to their chemical and structural composition, for example, an abundance of green photosynthetic pigment chlorophyll. For probing physical properties, ultrasonic sensors transmitting high-frequency sound, optical sensors, or laser sensors are being used to measure distances, height, and structure. These allow plant architecture and growth to be monitored. In isolation, each sensor is a powerful tool. When combined, these create a toolkit capable of overcoming the phenotyping bottleneck.



A high-resolution digital reconstruction of plant canopies. (Image by Jose Jimenes-Berni, CSIRO)

Rising to the challenge

With the right tools in place, the next challenge is to deploy them at scale. Over the past year, drones have appeared in the sky above IRRI headquarters in the Philippines. Drones provide an excellent means to collect data with which to sieve large collections of rice diversity for valuable traits. Fitted with RGB, spectral, and thermal-imaging sensors, the drone can collect data at the farm scale—measuring up to 100 hectares of rice in an hour. Cheap, fast, and highly mobile, drones have proven so successful that they will be deployed globally as part of the RICE–Global Rice Array, a network that brings together an international community of rice scientists to conduct a joint effort in enhancing the power of phenomics.

When working at the field scale, a GPS auto-steer tractor can be deployed. Eight sets of sensors are mounted on a 24-meter-long boom that sweeps over the canopy surface, collecting data as the tractor drives past. Moving at a speed of 1 kph, the system is capable of collecting canopy-level data on 2,500 plots per hour. Information from the onboard thermal, spectral, and ultrasonic sensors is used to perform digital growth analysis and monitor the responses of plants to the field environment. This system builds upon technology developed for a rainout shelter rack, a sensor-based system used for nondestructive monitoring of drought physiological experiments in a hydraulically controlled field environment.

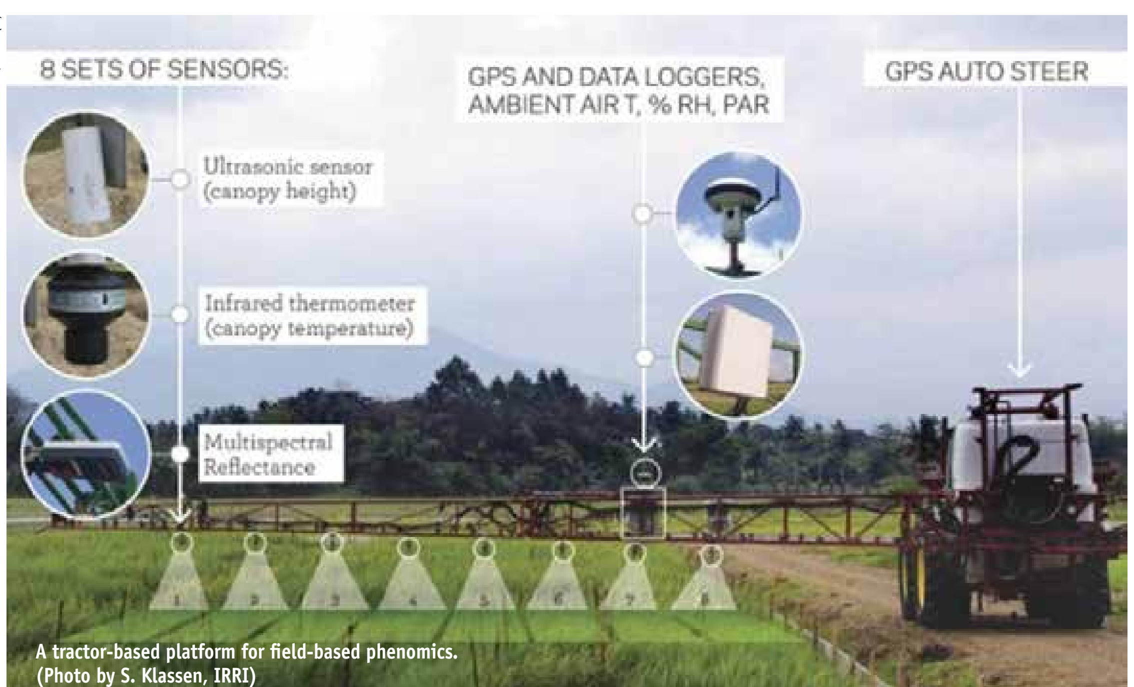
When more detail is required in order to dissect the mechanistic basis of a phenotype, the high-resolution phenotyping platform, built in conjunction with the High Resolution Plant Phenomics Centre at the Commonwealth Scientific and Industrial Research Organisation in Australia, is the tool of choice. Mounted on a gantry crane inside a screenhouse, this multi-sensor platform is capable of phenotyping 10,000 plants at the leaf level. Suitable for detailed trait dissection and probing dynamic responses, 3D images of plant canopies can be generated on which spatial data from color, thermal, and spectral sensors can be overlaid. By pushing the boundaries of innovation, this system aims to provide scientists with unprecedented amounts of detail and the ability to measure the components of complex traits such as photosynthetic efficiency and yield.

A window into the future

Phenomics is in a discovery phase; new technologies are being tested to see whether they are practical tools for phenotyping. IRRI is playing a key role in these innovations, investing in expertise and technologies that have led to significant increases in the number—and efficiency—of traits that can be measured. As the discipline develops, it will continue to redefine phenotyping capabilities. In this way, it will underpin the breeding of new rice varieties and drive improvements to rice production by enhancing the abilities of scientists and breeders to unlock rice genetic diversity. ■

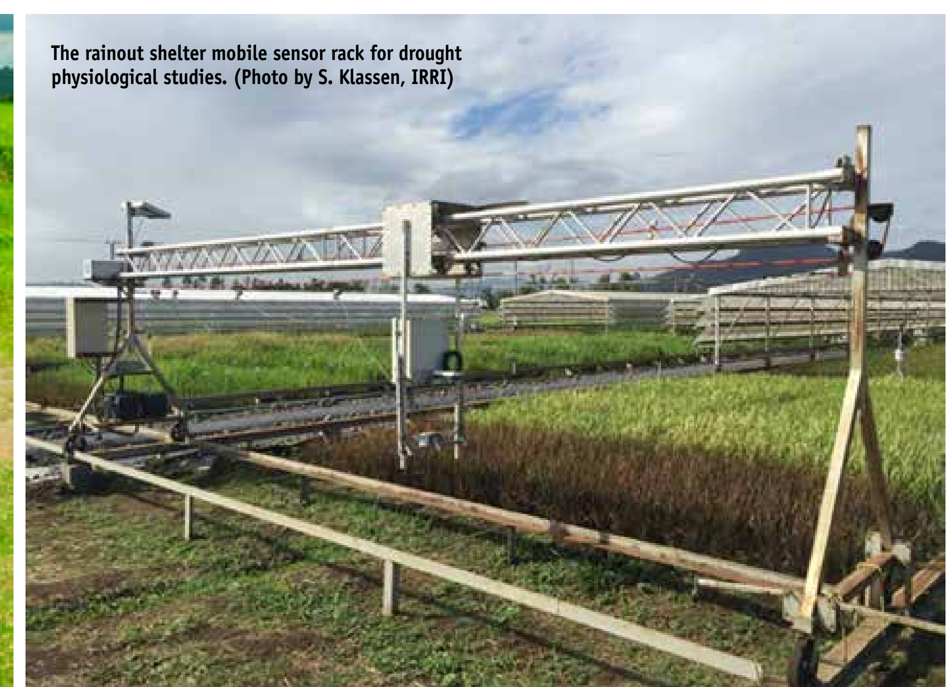
Drs. Coe and Quick are scientists at the C4 Rice Center at IRRI. Mr. Klassen an environmental science and engineering consultant at IRRI.

PHOTO BY STEVE KLASSEN, IRRI (3)



A tractor-based platform for field-based phenomics. (Photo by S. Klassen, IRRI)

Preparing the drone-based platform for flight. (Photo by S. Klassen, IRRI)



The rainout shelter mobile sensor rack for drought physiological studies. (Photo by S. Klassen, IRRI)

CRISPR-Cas system: Revolutionizing the genetic blueprint of rice

by Anindya **Bandyopadhyay**

Recent advances with the CRISPR system— the world's most promising gene-editing tool—could increase the speed of rice breeding.

One of the most discussed scientific events in today's world is the discovery and application of the clustered regularly interspaced short palindromic repeats (CRISPR) system in genome editing. CRISPR is simply a specialized bacterial immune system that scientists have modified into a tool for eliminating or manipulating the set of genetic instructions in animals, plants, and even humans. This tool is easy to use and cheap, which adds more value for this technology for rice scientists working on eliminating or modifying unwanted traits and inserting new traits to improve the crop's yield, resistance to diseases, and ability to thrive under harsh environmental conditions.

CRISPR 101

The CRISPR system has two components: a guide-RNA (gRNA) and a nuclease (Cas9/Cpf1). The gRNA carries the nuclease to target a certain location in a genome. After the gRNA reaches the target location, the nuclease attached to it can cut the genome at a desired location. This genome-editing process could be used to generate mutations arising from the cell's attempt to repair itself or introduce a piece of a new gene fragment into the cell.

A yogurt story

The bacteria containing CRISPR were discovered in a very unlikely place: the starter culture used in cheese and yogurt production. In the dairy industry, the starter culture for cheese and yogurt production uses *Streptococcus thermophiles*, a bacterium that converts lactose into lactic acid. *S. thermophiles* was prone to viruses (bacteriophage or phage-virus) that infect and spoil the culture. However, some bacteria in starter cultures were found to be capable of resisting bacteriophage attacks.

In the mid-2000s, scientists working at a Danish company that makes yogurt cultures traced the nature of the resistance of certain bacteria to the presence of CRISPR arrays in the bacterial genome, initially termed SPIDR (spacer interspersed direct repeats). When the bacteriophage attacks, the bacterium cuts a portion of the viral genome and incorporates it in its own genome in a special area called the CRISPR array. The incorporated bacteriophage genome acts as a guide to resist any subsequent attacks from similar viruses.

The discovery of this specialized immune characteristic of certain bacteria was later found to be extremely useful for genome engineering research. Dr. Jennifer Duodna and her team from the University of California, Berkeley, and subsequently Dr. Feng Zhang's group from the Broad Institute at Massachusetts Institute of Technology showed, respectively, that the CRISPR system can be used to precisely edit genomes of prokaryotes and eukaryotes.

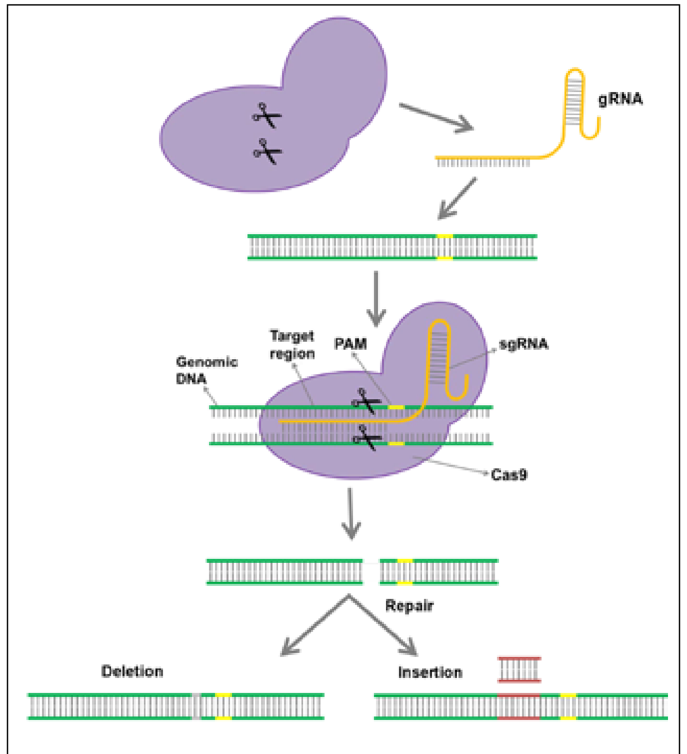
Diverse applications of CRISPR

The CRISPR system is highly versatile in its approach and applicability. With subtle changes in its general makeup, the CRISPR system can be directed to perform a variety of functions related to genome studies other than cutting and splicing DNA and removing and inserting genes.

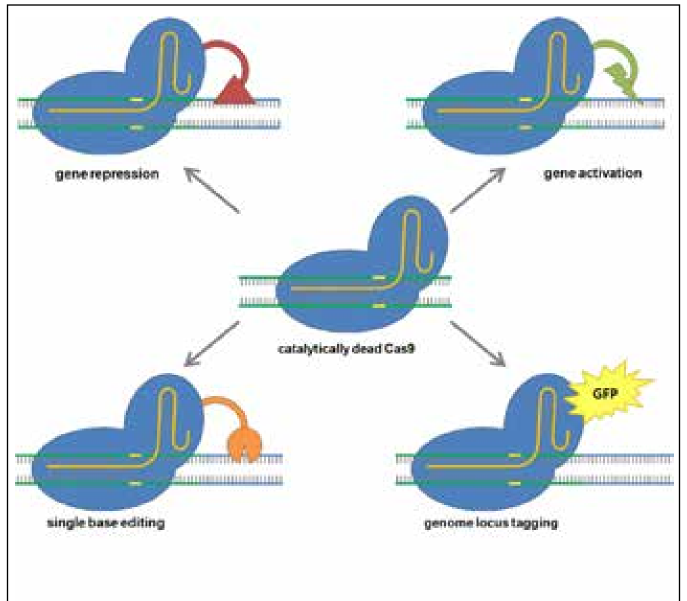
Scientists discovered that, by changing the structure of Cas9, they could modify its possibility to generate a catalytically dead version of Cas9 (or dCas9) that binds to the DNA double strand but does not manage to cleave it. When an inducer (a molecule that regulates gene expression) is attached to dCas9, it can bind at a particular location in the genome for which a target has been designed and induce the expression of a targeted gene. The same strategy can be used in turning off a targeted gene expression by replacing the inducer with a repressor. This has unprecedented use in gene tagging, screening, visualization, and other possibilities.

By disarming a single domain of Cas9, researchers could create Cas9 nickase (nCas9), which can cleave only a single strand of DNA for varied applications. Recently, specialized enzymes (cytidine deaminases) are being added to the dCas9, which can even edit at the single nucleotide level and can alter SNPs (single nucleotide polymorphisms).

One recent major development in the CRISPR toolbox is the application of purified Cas9 protein with a gRNA known as RNP (ribonucleoprotein), which can target the rice genome. As purified Cas9 is devoid of any foreign DNA, the mutants generated are completely free of genetic materials from unrelated species. Scientists are also trying to improve the delivery of

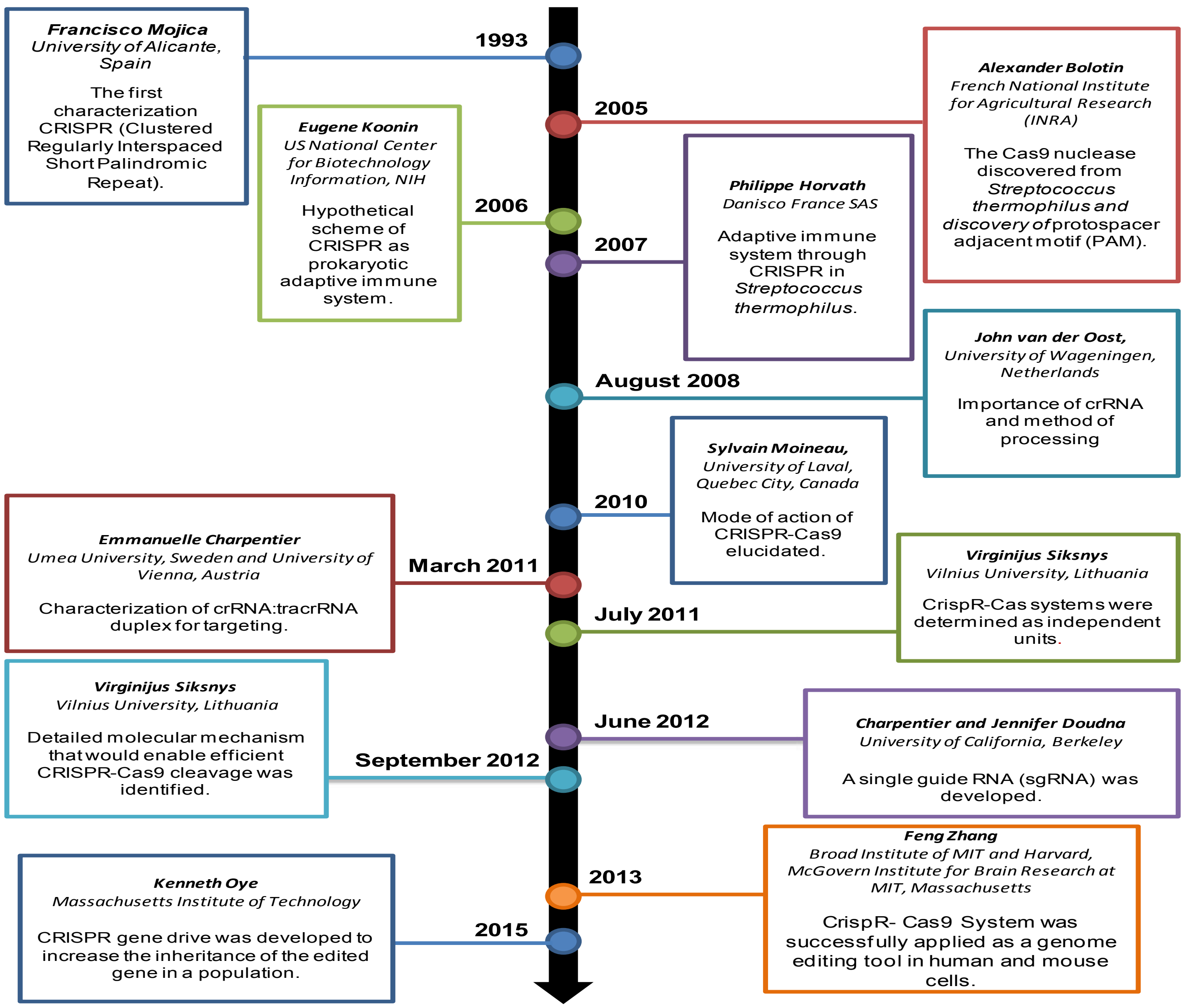


Mode of action of CRISPR-Cas9



Diverse applications of CRISPR-Cas9


Dr. Bandyopadhyay (right) and his team are pushing the rice-breeding envelope using the groundbreaking gene editing tool CRISPR-Cas9. (Photo by Isagani Serrano, IRRI)



Timeline of CRISPR

this RNP system via nano material-mediated cargo delivery. Ongoing research in this direction will soon refine this method for regular use.

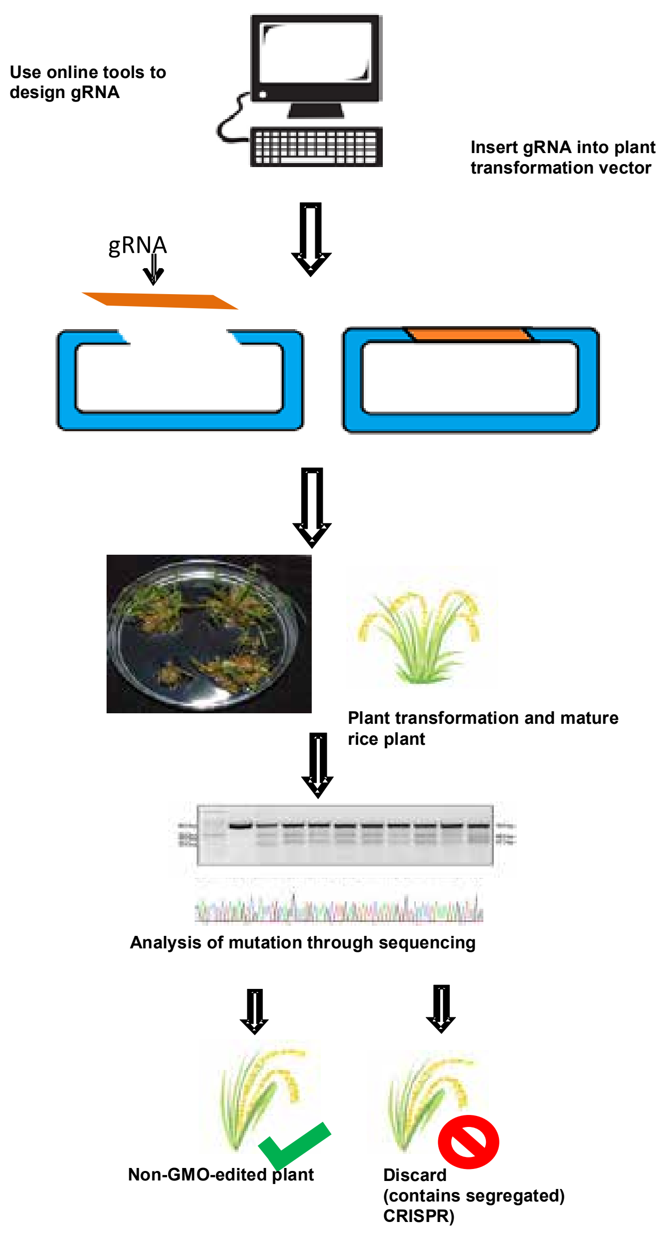
CRISPR and the rice challenge

As we know, rice is one of the most widely consumed and cultivated cereal crops in the world and has great economic and cultural importance for a large portion of the global population. It was inevitable that a research area as exciting and groundbreaking as CRISPR-based genome editing would find application in rice science.

Although genome editing in rice was already being practiced using other technologies, the CRISPR-Cas system provided unprecedented control and precision in creating targeted mutations in the rice genome. The CRISPR method could induce mutations with a very high efficiency. The focus soon shifted to the application of the CRISPR tool for the betterment of the rice crop as research moved toward the applied aspect of genome editing. In this regard, significant strides have been made toward improving rice and its traits.

The development of male sterile lines that are both light- and heat-sensitive was completed and validated using CRISPR. This development will be a massive boost to breeding because male sterile lines are important for rice breeding and hybrid development and the traditional method of creating male sterile lines is quite cumbersome.

Similarly, the CRISPR system has been used to develop rice lines that are more resistant to rice blast, a serious disease that destroys approximately 30% of global rice production. A private research company has also developed herbicide-resistant rice lines with the help of the CRISPR-Cas9 system. Rice



Workflow of a CRISPR experiment in rice

scientists are also looking at using the system to target multiple genes at the same time, resulting in newer traits in a single cultivar using fewer generations.

Interestingly, the mutations induced by the system are carried forward to successive generations and the CRISPR-Cas9 system gets segregated out. Thus, the mutants obtained are similar to mutationally bred nontransgenic crops with no genetic materials from unrelated organisms.

A promising toolbox

Our knowledge of the potential applications and repertoire of tools in the toolbox for tweaking genomes and creating targeted mutations is expanding day by day. For example, an enzyme alternative to Cas9 has been identified and has been successfully applied as an additional editing tool for rice. Known as Cpf1, it enables scientists to target locations in the rice genome inaccessible to Cas9, thus expanding the available targeting potential.

At the International Rice Research Institute (IRRI), the first report for using the CRISPR system in rice was published by the molecular editing team in the C_4 Rice Center in early 2017. The team used Cas9 and Cpf1 to edit the *OsEPFL9* gene, which determines stomatal formation and patterning, and create a mutation that causes *OsEPFL9* to lose its functions. Both Cas9 and Cpf1 were successfully used to edit the gene in question and create mutants. The mutants showed an 8-fold reduction in the number of stomata compared with that of a normal type. Manipulating the number of stomata, the tiny pores used by plants for gas exchange and transpiration, could improve the rice crop's efficiencyin using water. Further research in this area is ongoing and would be helpful in rolling out rice varieties with a stronger ability to survive droughts because of the more efficient use of the water stored inside the plants.

Other research activities at IRRI are also using CRISPR to manipulate other traits in rice to develop varieties that can withstand environmental stresses and pests and diseases, contain higher nutrients, and produce better grain quality. The system is also useful in developing doubled-haploid rice, which provides greater breeding efficiency. Clearly, the future of CRISPR and its application in rice for generating newer, better varieties of rice, the crop that feeds four billion people globally, is truly very promising. ■

Dr. Anindya Bandyopadhyay is a molecular biologist at IRRI.

The author would like to acknowledge Dr. Paul Quick, Shamik Mazumdar, Paolo Balahadia, Melannie Manguit Cabangbang, Dr. Xiaojia Yin, Dr. Abhishek Anand, other C_4 Rice Center staff members, and collaborator Dr. Julie E. Gray from Sheffield University.

Starving the foes: new ways to protect rice against diseases

by Veronica **Roman-Reyna**, Casiana **Vera Cruz**, and Ricardo **Oliva**

An innovative approach and a potential strategy to elevate resistance in crops against bacterial blight, a persistent enemy of rice.

IRRI scientists are rating the impact of bacterial blight on rice crop. (Photo by Eula Oreiro, IRRI).

Rice farmers know they will struggle against a ruthless adversary this monsoon season. Whether it is in Odisha in India, Central Java in Indonesia, or Mindanao in the Philippines, bacterial blight outbreaks are a common enemy during the rainy season. In irrigated environments, bacterial blight can easily spread across large cultivated areas, causing high economic losses. In fact, the disease has been a problem for the last decades in most tropical and subtropical rice-growing areas of Asia.

If the weather conditions are favorable and the rice variety is susceptible, farmers might notice tannish gray lesions growing along the leaf vein. Once the lesions appear, there is not much they can do; no chemical or other management control will stop the disease. Almost certainly, the lesions will spread out to cover the last leaf to emerge, known as the flag leaf, reducing its photosynthetic capability and compromising the plant's yield.

In that scenario, planting varieties resistant to bacterial blight is probably the most effective way to control the disease.

Major genes for resistance, called *Xa* genes (e.g., *Xa4*, *xa5*, *Xa21*), have been isolated and used in rice breeding programs. For instance, the widespread use of *Xa4* in the early 1980s provided an important level of protection to many rice mega-varieties, enabling them to succeed in favorable environments across Asia. Despite the important contribution of these genes in controlling the disease, one question persists: Why do many farmers still struggle with bacterial blight outbreaks every monsoon season?

The enemy adapted to resistant rice varieties

As any other harmful bacteria or pathogens, the invading organism that causes bacterial blight needs to steal nutrients from the host plant to survive. However, obtaining these nutrients is not an easy task since plants have a natural protection system that detects and destroys intruders inside and outside the plant. This is the plant immune system and most of the rice *Xa* genes that we know are part of it. The pathogens need to deactivate the protection layer to feed. But, not all pathogens are the same. Some have developed the ability to disable a particular *Xa* gene and spread. This is the reason some resistance genes are no longer effective against bacterial blight in Odisha but continue to be useful in Central Java.

Starving the enemy

Since some pathogens have "learned" to bypass the immune system, scientists are exploring new strategies to protect rice. One way of reducing the infection is by blocking the pathogen's access to nutrients to starve the pathogen, leaving it with no source of energy needed for growth. As far as we know, the pathogens do not have the means to deal with nutrient restrictions.

This is an innovative approach and a potential strategy to elevate disease resistance in crops. To validate this concept, several scientists at the International Rice Research Institute (IRRI) are using genome editing techniques to target plant nutrient-related genes and induce starvation in the bacteria at the onset of the disease. The scientists have found that making minimal changes at the DNA level is enough to block the nutrient flow and reduce bacterial growth without affecting yield. This work is part of a research consortium involving national partners in Asia and Africa, universities, and CGIAR centers.

Moving into the breeding program

For the past two years, IRRI scientists have been looking for natural variations that mimic the so-called starvation phenotype. Interestingly, they have found two landraces among thousands of rice accessions that naturally block

Rice plants with advanced symptoms of bacterial blight. (Photo by Nancy Castilla, IRRI).

nutrient flow toward the infection. These plants carry small variations in nutrient-related genes, which are enough to limit the growth of a broad population of bacterial blight pathogens. These are promising alternative ways to increase plant resistance without relying solely on the plant's immunity system.

The same strategy has been reported in other cereals in which disease symptoms cannot spread and the plant maintains high yield. Breeders at IRRI have started to move these novel genes into elite accessions, expecting to achieve durable resistance.

These are exciting times. This strategy represents our best chance to substantially reduce bacterial blight epidemics. Hopefully, the time will come when farmers in rice-growing areas across Asia will no longer dread the rainy season and their bacterial nemesis. ■

Dr. Roman-Reyna is a Postdoctoral Fellow, at IRRI. Drs. Vera Cruz and Oliva are plant pathologists at IRRI.

Want more *Rice Today*?

Subscribe to *e-Rice Today* for FREE.
See bitly.com/e-RT.

Orlando Peixoto de Morais
(1949-2017)

The most outstanding rice breeder in Brazilian history started a new era of rice cultivars and leaves behind a legacy that transcends boundaries.

by Élcio Perpétuo **Guimarães**

Dr. Orlando Peixoto de Morais was a plant breeding icon in Brazil and the mastermind of the rice breeding program at Empresa Brasileira de Pesquisa Agropecuária (Embrapa). In fact, from the numerous messages Embrapa received regarding his passing, many of his colleagues consider him the most outstanding rice breeder in Brazilian history.

Life brings challenges to all of us, but Dr. Morais transformed his challenges into opportunities. Born and raised on a farm, he faced the difficult life of living in a city with few financial resources to obtain his degree in agronomy at the University of Viçosa in Minas Gerais. Notwithstanding, he quickly built a reputation among his fellow students, many of them coming to him for help in different disciplines, especially those related to quantitative genetics. This was not only because of his impressive knowledge but also because of his remarkable patience and willingness to help. Dr. Morais was literally a point off the curve so that some of his professors had to grade him separately to avoid skewing the grade distribution of all other students downward.

As soon as he started working as a rice breeder at the state research institution Empresa de Pesquisa Agropecuária de Minas Gerais, the country started seeing a new era in the development of rice cultivars, which made a huge impression on the country's rice value chain and consumers.

In 1984, the upland rice cultivar Guarani was released. Guarani, a high-yielding short-cycle upland rice for midwestern Brazil with good cooking quality and blast and drought resistance, was planted on millions of hectares.

The biggest impact on Brazil's rice production was attained with cultivar BRS Primavera. Released in 1997, it was the first upland cultivar that was comparable with irrigated rice in terms of grain quality and commercial value. It also set the new standard for upland varieties in Brazil. The production of high quantities of good-quality rice has strengthened the entire rice value chain in the region, making it self-sustaining.

Over the past few years, Brazil's rice breeding program experienced increasing gains in grain yield, nearly 1.5% per year.

Dr. Morais developed several methods to enhance breeding strategies and calculate the genetic gains of breeding programs, both ex ante and ex post. These studies allowed breeders to improve the design of their breeding programs as well as estimate the impact of improved varieties. The successful application of recurrent selection to Embrapa's rice breeding program, another major technical innovation introduced by Dr. Morais, is delivering higher genetic gains for yield than other rice breeding programs around the world.

Outside technical aspects, Dr. Morais had outstanding networking skills. He put his easygoing personality to the service of the national rice breeding network, which consequently became more united and efficient in working together and achieving genetic progress. ■

Dr. Guimarães is the communication supervisor at Embrapa Rice and Beans.

Equipped with multiple cameras and sensors, the high-resolution phenotyping platform collects plant growth, performance, and composition data as it sweeps over the rice canopy. It provides scientists the ability to collect unprecedented amounts of information from a single experiment. (See story on page 5). Photo by Robert Coe, IRRI

Africa's new roots

by Paula Bianca **Ferrer**

Can Africa be the next global rice production frontier?

PHOTO BY RENE GUEVARRA, IRRI

In the next decades, another 40 million tons of rice will be needed to feed an ever-growing population. But, where will this growth in production come from when land, water, and other resources are becoming increasingly limited in many rice-producing countries? Experts are therefore pondering whether Africa can be the next frontier when it comes to global rice production.

All too often, Africa's landscape conjures images of arid and unforgiving parched lands, where only the toughest flora and fauna are able to survive. Despite this challenging situation, many African countries, through extensive training that builds the capacity of its rice value chain, are spreading the new roots of a Rice Revolution.

Card of fortune

In 2008, the Japan International Cooperation Agency (JICA) launched the Coalition for African Rice Development (CARD) as a comprehensive initiative to support the efforts of African member countries to double their rice production in the next 10 years.

"One of the first initiatives of CARD was to start within each of the member countries a process of building a strategy for rice development," shared Jason Beebout, project manager for the partnership between JICA and the International Rice Research Institute (IRRI) to build the capacity of CARD countries in producing, maintaining, and promoting the use of good-quality rice seed. "This is developed by a task force within the country.

"It's a concrete commodity-based rice strategy in which all the sectors of the rice value chain starting from seed and fertilizer and going all the way into the production process, postproduction processing, access and marketing, finance, and policy were looked at and elaborated into a rice development strategy," he said.

Out of a total of 23 CARD member countries, 22 have developed and validated their national rice development strategies.

Seeds of change

Having limited access to and supply of good-quality seeds were identified as significant factors limiting increasing rice production. So, a pilot initiative to develop a roadmap for rice seeds was launched in about 10 countries. The roadmap dovetailed into improving both the quality and quantity of rice seeds, in addition to developing the channels to give good-quality seeds to farmers.

"Capacity building of relevant stakeholders was a crucial aspect of the initiative," Mr. Beebout said. "In response, a proposal initiated by Dr. Noel Magor, the previous head of IRRI's Training Unit (now IRRI Education), was presented during the Sixth General Meeting of CARD in 2015. The contract between IRRI and JICA was signed in March 2016."

One key component of this capacity-building program is an eight-week training course on rice seed production and extension hosted and implemented by the Philippine Rice Research Institute (PhilRice) in Nueva Ecija.

Flow of insight

"A lot of information and knowledge have been imparted to us," shared Brenda Kisingiri, an inspector in the Department of Crop Inspection at Uganda's Ministry of Agriculture. She is one of 19 Africans nominated by focal persons in CARD member countries to train at IRRI and PhilRice this year.

"We've had gaps in rice production and we're realizing our targets as a country," Ms. Kisingiri said. "One of the major gaps was the availability of good-quality seeds for the farmers when they needed them. This course was pertinent, particularly in our ministry, as we are supposed to make sure that seeds are available."

She added that her department manages the certification process for good-quality seeds and provides training for seed companies and farmers. "It's a complete package that I'm taking back to my colleagues," Ms. Kisingiri said. "We'll try to take it to the seed companies, farmers, and traders. This has been one of the best courses I have attended and I hope it continues into the future."

Field of dreams

"This training was important to me as an extensionist," observed Michael Shitabule. Mr. Shitabule comes from one of the 47 counties in Kenya. "I want to start with my own county. I want to see if yields will improve because of other issues that are also pertinent to rice production. Even if we have a lot of good-quality seeds, if other problems are not addressed, you won't get good yields.

"A lot of factors can contribute to yields, so I want to look at what I already have as an extensionist," he said. "I do not want to go into breeding. I just want to look at the extension package. How can I improve on what is available? From there, I know what I will do. I want the simplest way I can explain to a farmer."

He looks at PhilRice's *Palaycheck System for the Philippine Irrigated Lowland Rice* as a potential model for his extension work. The system packages eight best key technologies and management practices as Key Checks:

1. High-quality seeds of a recommended variety
2. Field leveling
3. Synchronous planting after a fallow period
4. Healthy seedlings
5. Sufficient nutrients at tillering to early panicle initiation and flowering
6. Water management to avoid excessive water or drought stress that could affect the growth and yield of the crop
7. Pest management to reduce yield losses
8. Harvesting and threshing the crop at the right time

It also compares farmers' practices with the best practices and learns through farmers' discussion groups to sustain improvements in productivity, profitability, and environmental safety.

"I worry that, in the first season, the farmer is not going to understand what I've been explaining to him," Mr. Shitabule said. "But, in time, maybe he will understand. We will do it step by step until we reach key check 8 and we harvest at the right time."

Grains of promise

"We have been shown the picture of rice production trends in the world," said Ms. Kisingiri. She was impressed that a major crop had an institution supporting its production as well as the commitment of the Philippine government.

"Research is producing the technologies for both seeds and equipment," she observed. "But, they make sure they pass on this information, for example, to PhilRice. Then PhilRice makes sure that it goes through the various channels, such as farmer field schools, digital applications, and others, through which farmers can access the information."

Her new knowledge has fired up Ms. Kisingiri's determination: "We have realized that African countries should now rise up to the challenge because we are probably the ones to fill the gap in the rice supply that the world needs to overcome. We are going to go back and look at each of our national rice seed strategies and see what is keeping us from moving forward and where we can contribute." ■

Ms. Ferrer is a science communication specialist at IRRI.

Africa, which has tremendous agricultural potential, is often described as a continent of paradoxes. Rice statistics reveal one such paradox. The continent's average rice yields, estimated at about 2 tons per hectare (ha), are among the lowest in the world. Yet, Egypt, in northern Africa, has one of the highest national average rice yields worldwide, with nearly 10 tons per ha.

Egypt's rice yields were boosted by the use of high-yielding inbred and hybrid varieties, according to the Food and Agriculture Organization of the United Nations. Egypt is the only country in Africa that has successfully produced several varieties of hybrid rice with grain yield of 12–14 tons per ha. It has also developed a strategy to produce hybrids tolerant of salinity and drought.

It is no wonder that Egypt is also the only country on the continent that produces enough rice for its domestic demand, with a surplus for export. It was inspired by China, where hybrid rice has contributed significantly toward improved food security, environmental protection, and job creation since the early 1980s.

Exploring hybrid rice potential in Africa

Most African countries are still far from self-sufficient in meeting their rice demand. In 2013, Africa imported 14 million tons of milled rice at a cost of USD 7.5 billion. The continent, therefore, needs to urgently improve rice productivity to reduce its heavy dependence on imports.

As a result of heterosis (hybrid vigor), hybrid rice shows a yield advantage of 15–20% over the best inbred variety grown under the same conditions. It can provide an avenue for African rice farmers to raise their rice yields and profitability.

"Hybrid rice is also more competitive with weeds—a major constraint, particularly in direct-seeded rice," explained Raafat El-Namaky, a hybrid rice breeder at the Africa Rice Center (AfricaRice).

THE HYBRID ALTERNATIVE FOR AFRICA

by Savitri **Mohapatra**

African farmers inspecting the early-maturing and high-yielding hybrid rice varieties developed by AfricaRice at Saint Louis, Senegal. Hybrid rice can provide an avenue for the farmers to raise their crop yields and profitability. (Photo by R. Raman, AfricaRice)

Hybrid rice technology, however, faces some major challenges. Farmers have to buy fresh seed every cropping season because hybrid grain will not breed true if used as seed. Also, because of the high cost of hybrid seed production, hybrid seed is usually quite expensive. To make it economically viable, it is necessary to raise the yield of hybrid seed production to at least 2–3 tons per ha.

"Hybrid rice seed production can thus be a profitable business," Dr. El-Namaky added. "Moreover, as it requires intensive labor input, it can create employment opportunities for Africa's youth."

Hybrid rice could also help African rice farmers get used to certified seeds because it is necessary to renew the seed every year. "In Africa, most farmers tend to use their own varieties and seed, despite the availability of improved seed; consequently, yields are low," said Dr. El-Namaky.

The AfricaRice strategy: hybrid rice for sub-Saharan Africa

Green Super Rice (GSR) project: Since 2008, AfricaRice has been involved in evaluating Chinese hybrid rice lines in sub-Saharan Africa (SSA) through the GSR project to make Chinese rice cultivars (inbred and hybrid varieties) accessible to rice farmers in Africa and Asia. The project is coordinated by the Chinese Academy of Agricultural Sciences, the International Rice Research Institute (IRRI), and AfricaRice.

In the first phase of the project, most of the Chinese cultivars evaluated in SSA confirmed their high yield potential but succumbed to African insect pests and diseases. The second and third phases of the project are using African rice germplasm and GSR lines as donors for local adaptation. The project also conducts training in hybrid rice seed production.

AfricaRice hybrid breeding program: In response to the interest of its member countries, AfricaRice established its own hybrid rice breeding program in 2010 at its regional station in Saint Louis, Senegal.

To date, more than 500 hybrids and their parental lines have been developed and evaluated on-station in Saint Louis under irrigated and rainfed lowland conditions. About 50 hybrids showed a 15–20% (1.0–1.5 tons per ha) yield advantage over the inbred check. Most of them are early-maturing (110–120 days) and high-yielding (10–13 tons per ha).

"This will allow farmers to obtain high yield and grow two crops per year," said Dr. El-Namaky. He added that most of these hybrids have good grain quality traits (medium and long grains with intermediate to high amylose content). Their milling percentage (degree of recovery) is more than 67% compared with 65% for the inbred check.

Developing the hybrid rice technology capacity of national partners, farmers, nongovernment organizations, and the private sector is a major component of the AfricaRice strategy. A new set of rice hybrids, with seed yield ranging from 2.0 to 3.5 tons per ha, developed by AfricaRice is being evaluated with public and private seed companies in Burkina Faso, Kenya, Mali, Mauritania, Nigeria, Senegal, and Uganda. A roadmap for hybrid rice testing, release, and dissemination in Nigeria and Mali has been developed. Technical backstopping and training on hybrid rice seed production are being provided.

"We insist that local companies be trained to produce hybrid seed within the subregion," said Dr. El-Namaky. "Otherwise, if hybrid seed is brought from Asia, there is a risk that rice diseases from Asia would spread here through the seed."

Farmers' choice

More than 100 farmers who participated in the hybrid selections over the past three years showed a keen interest in these hybrids. Out of the eight promising hybrids they selected on-station, four were grown in large demonstration plots in farmers' fields in Saint Louis. Two high-yielding and early-maturing hybrids—AR032H and the aromatic AR051H—were selected for release in Senegal.

"I would like to grow this type of rice so that I can earn more," said Mrs. Sahibatou Gueye, a local rice farmer, after inspecting the hybrids.

Mr. Abdoulaye Faye, a farmer-entrepreneur, said the hybrids should be made available to farmers as quickly as possible, along with supportive measures from the government and training of farmers in seed production.

Mr. Omar N'daw Faye, head of the rice breeding unit at the Senegal Institute for Agricultural Research, assured that the selected hybrids would be released shortly in the country. "We also need to urgently build our national capacity in hybrid rice technology so that we can support our farmers and seed producers."

The way forward

AfricaRice will continue to support areas that are key to a successful hybrid rice program: establishing an efficient seed industry, developing high-performing hybrids, and improving capacity development.

AfricaRice is strengthening its collaboration with many partners, particularly through its participation in the Hybrid Rice Development Consortium (HRDC) coordinated by IRRI. HRDC aims to strengthen collaboration between the private and public sector and improve hybrid rice technology dissemination.

The center believes that hybrid rice technology can help leverage private-sector investment in rice research and development in Africa. It will also advocate for increased public-private partnerships and government support to hybrid rice technology in SSA.

"We encourage all partners to work with us, particularly the private sector, as it has more experience and capacity in this area," said Dr. El-Namaky. ■

Ms. Mohapatra is the head of Marketing and Communications at AfricaRice.

Improving health and nutrition through rice science

by Elemarie **Lamigo-Rosellon**

PHOTO BY ISAGANI SERRANO, IRRI

Mallikarjuna Swamy, head of the Healthier Rice Breeding Group at the International Rice Research Institute (IRRI), shares his thoughts on the role of science in solving malnutrition, particularly zinc deficiency.

"More than two billion people in the world are malnourished and most of them live in rice-consuming Asian countries," says Dr. Swamy. He adds, however, that huge opportunities exist to improve the nutritional content of rice varieties to solve the micronutrient-deficiency problem. Scientists at IRRI and its partners are working together to bring solutions such as the high-zinc rice varieties that have been released in the Philippines and Bangladesh.

A molecular biologist, Dr. Swamy joined IRRI in 2009 and served as a postdoctoral fellow in a rice breeding program on drought. He identified quantitative trait loci and introduced these into several popular rice varieties to develop drought-tolerant ones. In 2013, he was selected as a breeder in the institute's biofortification program to develop high-zinc and vitamin A-enriched rice varieties for South and Southeast Asian countries.

What problem are you trying to solve through your project at IRRI?

Micronutrient deficiency, also called hidden hunger, is a major nutrition problem affecting more than two billion people worldwide, especially in Asian countries, where rice is the major staple food. This is because most of the popular rice varieties grown and eaten by billions of people lack a sufficient amount of minerals and vitamins. Health problems from deficiencies in iron, zinc, and vitamin A are highly evident in Asian populations. Children and pregnant and lactating women are especially vulnerable to malnutrition.

The United Nations has identified overcoming the problem of micronutrient malnutrition as one of the major sustainable development goals to be achieved by 2035. For a major problem like this, science is essential. IRRI, being the leading research center for the development of rice varieties, has helped solve many problems through scientific interventions. Our project aims to develop more nutritious rice varieties as part of a bigger strategy for counteracting global hidden hunger.

How important is dietary zinc?

Zinc is needed for the body's immune system to properly work. The absence or deficiency of zinc causes stunting, diarrhea, reduced immunity, and poor cognitive development. It plays a key role in cell division, cell growth, healing of wounds, and the breakdown of carbohydrates. It is a major part of more than 300 enzymes of the human body, so enzymatic activities in the body need zinc as a catalytic compound, making it a requirement for normal growth and development. Its importance to the body's various biological systems makes getting an adequate amount of zinc in our daily diet a must.

How was high-zinc rice developed?

Our group is focusing on developing rice varieties with a higher content of zinc than the popular varieties. We are using conventional breeding methods, transferring the trait from new high-zinc donor lines that we have identified. We have already released a high-zinc variety in the Philippines and three varieties in Bangladesh in collaboration with our partners, the Philippine Rice Research Institute (PhilRice) and Bangladesh Rice Research Institute.

The team identified some high-zinc donor lines and crossed these with popular rice varieties grown in the Philippines. After making selections over several generations, we identified a line with high zinc and good agronomic characteristics. These selected lines were planted in multi-location field trials in the Philippines through the National Cooperative Testing (NCT) Project on Rice supported by PhilRice. This line passed the NCT trials as having higher zinc than popular varieties and it was approved for release. There is no difference in taste, aroma, or color from those of other popular varieties.

What are your major challenges in developing more nutritious rice varieties?

For science-based interventions, the beginning stage always comes with many challenges. Developing rice varieties with the right combination of good traits (high yield, resistance to pests and diseases) with improved nutrition is one of the major goals. Identifying the donor lines carrying the most stable high-zinc trait was one of the challenges.

Another challenge is mainstreaming this high-zinc trait in the varieties that IRRI will release in the future. That means all the new varieties will carry improved nutritional content together with high yield-potential, stress-tolerance and disease-resistance. However, we first need to identify the molecular tools to track the genes for high zinc. Developing the molecular tools, generating resources, and widely disseminating this information will take several years.

How do you measure the impact of healthier rice varieties?

We anticipate that the knowledge generated and the products developed under our project will have a huge impact that can be measured in several ways: successful development and release of healthier rice varieties; their adoption in areas where deficiency is common; improved health and nutrition of rice consumers, especially children and women; reduced cost of healthcare; improved income, education, and social status; reduced gender inequalities; and healthier societies.

The Philippines celebrates Nutrition Month in July. What do you think are the nutritional challenges in the country?

Although high health awareness exists among the Filipino people, the problem is that what people are eating does not have the right content of micronutrients. Most of the popular varieties grown and consumed in the Philippines are low in micronutrients. If we increase the content of micronutrients in rice, naturally people will be consuming more micronutrients.

When was the high-zinc rice variety released in the Philippines?

This first high-zinc rice variety, High Zinc Rice 1, was released in 2016. The seeds are available at PhilRice. There are plans to multiply and distribute the seeds and disseminate this rice variety in the country.

What should people know about the development of healthier rice?

Healthier rice varieties are one of the most sustainable and cost-effective approaches in tackling malnutrition. Because billions of people eat rice every day, this will improve the health status of the general population if you supply these nutrients through their staple diet. The compelling story is that we are making much progress in developing healthier rice at IRRI. This information must be communicated widely. There is a need to share the story.

What are your team's other targets at IRRI?

We want to combine multiple healthier elements in the future. Now, we treat zinc, iron, and vitamin A separately using different approaches. We want to combine them, to give a daily dose of these important micronutrients with each serving of rice. We will continue to work on adding nutritional improvements to all the other productivity benefits of new rice varieties. ■

Ms. Lamigo-Rosellon is a communication specialist at IRRI.

by Robert Coe & Ando Mariot Radanielson

WINNING SCIENCE

Meet the awardees of the first IRRI Seed Grant Scheme

The International Rice Research Institute (IRRI) delivers through research excellence. The IRRI Seed Grant Scheme was launched in early 2017 to foster innovative collaborative research among young scientists. Following a competitive peer-review process, six research teams were awarded USD 15,000 each to undertake cross-disciplinary and innovative research over the next 9 months. Meet the principal scientists and hear the stories behind their winning proposals.

PHOTO BY: ROBERT COE, IRRI (3)

TRANSFORMING RICE PRODUCTION TO IMPROVE THE LIVELIHOOD OF FARMERS

Nitika Sandhu

The rapid urbanization of major rice-growing regions is limiting farmers' access to land, labor, and resources such as water. As a response, the traditional method of transplanting rice seedlings is being replaced by directly sowing seeds in the field. This is less labor intensive, uses less water, and leads to faster crop establishment. However, directly sowing seeds may lead to uneven germination, decreased survival, increased competition from weeds, and lower crop yields. Dr. Sandhu aims to transform rice production systems to help poor farmers struggling to cope in a changing world. She has formed a collaborative research team with experts in plant breeding, soil chemistry, and growing rice in unfavorable environments. The team will examine issues associated with variable seedling sowing depth and its effect on nutrient uptake in relation to water content. The research aims to identify rice varieties and develop management practices that lead to high rates of germination and emergence and better crop establishment under direct seeding. The ultimate goal is to increase the yield and profitability of farmers through the adoption of mechanized direct seeding.

A SCHEDULE FOR HARVESTING SUCCESS

Huang Van Nguyen

The rising cost and shortage of labor mean that combine harvesters are increasingly being used to harvest paddy rice. Machines are usually shared among many farmers, leading to competition for access during busy periods. If access to machines is not scheduled well, farmers can experience high crop losses and excessive harvesting costs. To overcome this problem, the research team aims to develop a system called *EasyHarvest*. This will optimize the scheduling of combine harvester services so that the needs of farmers can be matched to the availability of contractors and equipment. By combining predictions of harvesting times and the availability of combines, the harvesting requirements of farmers can be efficiently managed. This system also offers the potential to monitor and forecast the dates for harvesting rice, allowing farmers to plan well in advance. *EasyHarvest* could cut postharvest losses by 3% and farmers' costs by as much as 10%. It could also help reduce the environmental footprint of harvesting by using machinery more efficiently and effectively. If the proof-of-concept trials at IRRI are successful, the system could be scaled up to the national level and used to schedule access to any machine used in rice production.

EMPOWERING RICE FARMERS WITH INFORMATION TECHNOLOGY

Harold Glenn Valera

Dr. Valera, a social scientist with expertise in gender research, aims to empower rice farmers in the Philippines by increasing their access to information technology. Rice Crop Manager is a decision-support tool developed to help farmers increase their yield and profitability by providing them with tailored crop management advice. It has been estimated that using the tool could increase rice yields by 300 kg and farmers' income by about USD 80 per hectare. Through surveys, Dr. Valera aims to evaluate the behavior of men and women farmers toward the information provided by the tool. He will assess differences in perception and understanding of the information it provides and how these affect implementation of its recommendations. By bringing together experts in social science, information and communication technology, and agriculture, this research will highlight the effectiveness of agricultural extension: the ability of scientific research and knowledge to educate farmers. The outcomes will be a series of recommendations that will enhance the dissemination of ICT tools such as Rice Crop Manager. In turn, this will allow for the full increase in yield and profitability that these tools offer.

SOFTWARE TOOLS TO ACCELERATE RICE BREEDING

Dmytro Chebotarov

Dr. Chebotarov, a bioinformatician and statistician, wants to develop a software tool that will help scientists and breeders deliver the

PHOTO: IRRI

next generation of rice varieties. The genome of a rice plant is a unique sequence of genetic code that acts as a blueprint or set of instructions that controls every aspect of the plant. With sequencing, it is possible to read this code and identify variations known as single nucleotide polymorphisms (SNPs). SNPs can be used to understand why rice varieties differ from one another. Generating sequence data can be costly and so, often, only a partial sequence—akin to a fingerprint—is obtained. When this approach is taken, scientists are forced to limit the number of variants they can measure. Reaching a meaningful trade-off between cost and the potential value of the data is extremely challenging. To help make this decision, Dr. Chebotarov and his team aim to develop a software tool called MAPPA. This will enable scientists to maximize the value of their data while minimizing the cost of sequencing. MAPPA will exploit the information from the variants measured by ensuring that these are well-distributed within the genome while being informative. Apart from saving scientists money, the real value of the tool is in increasing the amount of information available to scientists and breeders, which, in turn, will increase the speed and efficiency of introducing agriculturally desirable traits into new rice varieties—and benefit rice farmers and consumers alike.

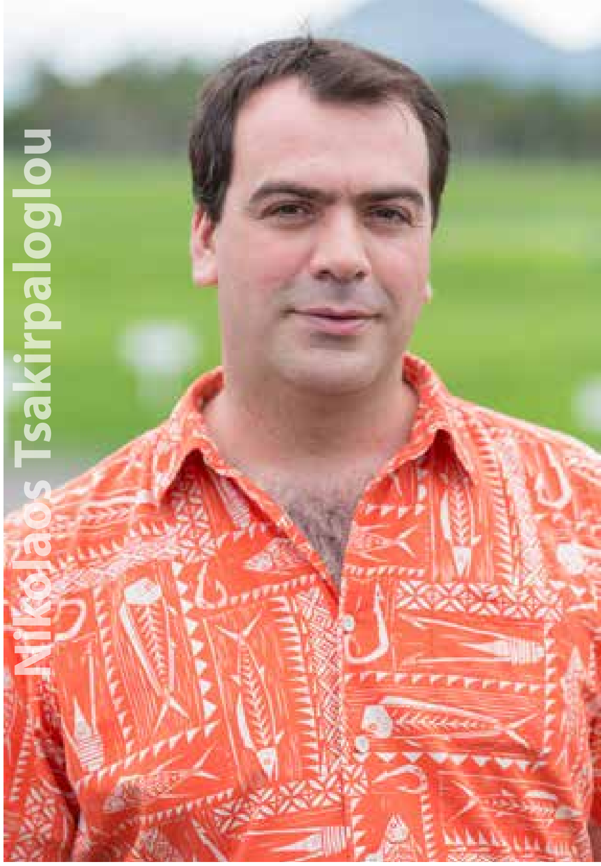


PHOTO BY: ISAGANI SERRANO, IRRI

SAFEGUARDING THE FUTURE OF RICE NUTRITIONAL QUALITY

Nikolaos Tsakirpaloglou

Dr. Tsakirpaloglou is a molecular biologist who aims to safeguard the nutritional quality of future rice varieties to help fight malnutrition. To alleviate global deficiency in iron and zinc, IRRI has produced biofortified rice lines that provide up to 30% of the estimated average requirements of these micronutrients. These lines are set to play an important role, particularly in rural regions and poverty-stricken urban populations, where traditional micronutrient intervention strategies are less effective. Recent evidence suggests that iron and zinc content in cereal grains may decrease in the future as a result of climate change. Working with scientists from the C_4 Rice Group, Nikos's research aims to evaluate the performance of biofortified lines under future climate conditions. The results will enable the selection of appropriate geographical zones to ensure the maximum impact of biofortified lines in the coming decades. It will also call for the development of new strategies to mitigate micronutrient deficiency in a world experiencing extreme changes in climate.

USING LESSONS FROM THE PAST TO DRIVE THE FUTURE OF RICE BREEDING

Hsiang-Chun Lin

Dr. Lin, an expert in applied photosynthesis and systems modeling, aims to exploit rice evolution to drive the future of rice breeding. Chloroplasts are one of the most important biological machines on Earth. Present in all plant cells, they convert sunlight into energy through photosynthesis. In turn, this energy is supplied to the powerhouses of the cells, the mitochondria. These two remarkable structures are the result of an evolutionary relationship between early plant cells and oxygen-using photosynthetic bacteria. As a result, chloroplasts and mitochondria have their own genetic code (DNA), which is different from that of the rest of the plant. Because of the important role these structures play, a variation in the genetic code between rice varieties could lead to major differences in important agricultural traits that affect growth, biomass production, and yield. In a unique collaboration between bioinformaticians and biologists, Dr. Lin's research aims to compare the DNA of 3,000 rice varieties and identify variations called single nucleotide polymorphisms (SNPs). This information will enable her team to understand the diverse function of rice and understand the evolution and history of rice domestication, which will help to identify lines that can be used to breed new varieties with improved agronomic traits. It will also help scientists understand the evolution and history of rice domestication, information that will inform the breeding process. ■

Dr. Coe is the leader of the C4 Rice Center Phenomics Group at IRRI. Dr. Radanielson is a cropping systems scientist at IRRI.

SELECTED PUBLISHED ARTICLES BY IRRI STAFF

Over the first six months of 2017, IRRI staff have published 115 research articles. This list presents some of the articles.

Akter, Sonia, Pieter Rutsaert, Joyce Luis, Nyo Me Htwe, Su Su San, Budi Raharjo, Arlyna Pustika **Women's empowerment and gender equity in agriculture: A different perspective from Southeast Asia** *Food Policy 69 (2017): 270-279.* doi:10.1016/j.foodpol.2017.05.003

Ali, Jauhar, Jian-Long Xu, Yong-Ming Gao, Xiu-Fang Ma, Li-Jun Meng, Ying Wang, Yun-Long Pang, Yong-Sheng Guan, Mei-Rong Xu, Jastin E. Revilleza, Neil J. Franje, Shao-Chuan Zhou, and Zhi-Kang Li. **Harnessing the hidden genetic diversity for improving multiple abiotic stress tolerance in rice (Oryza sativa L.)** *PloS One 12, no. 3 (2017): e0172515.* doi:10.1371/journal.pone.0172515

Anisuzzaman, M., MM Emam Ahmed, Partha S. Biswas, and Md Ansar Ali **Multi-environment variety testing (Pre-Met) for irrigated ecosystem in rice (Oryza sativa L.)** *International Journal of Sustainable Agricultural Research 4, no. 1 (2017): 9-15.* doi:10.18488/journal.70/2017.4.1/70.1.9.15

Bheemanahalli, Raju, Rajendran Sathishraj, Muthukumar Manoharan, H. N. Sumanth, Raveendran Muthurajan, Tsutomo Ishimaru, Jagadish S.V. Krishna **Is early morning flowering an effective trait to minimize heat stress damage during flowering in rice?** *Field Crops Research 203 (2017): 238-242.* doi:10.1016/j.fcr.2016.11.011

Brozynska, Marta, Dario Copetti, Agnelo Furtado, Rod A. Wing, Darren Crayn, Glen Fox, Ryuji Ishikawa, and Robert J. Henry **Sequencing of Australian wild rice genomes reveals ancestral relationships with domesticated rice** *Plant Biotechnology Journal 15 (2017): 765-774.* doi:10.1111/pbi.12674

Brozynska, Marta, Dario Copetti, Agnelo Furtado, Rod A. Wing, Darren Crayn, Glen Fox, Ryuji Ishikawa, and Robert J. Henry **Sequencing of Australian wild rice genomes reveals ancestral relationships with domesticated rice** *Plant Biotechnology Journal 15 (2017): 765-774.* doi:10.1111/pbi.12674

Burman, D., B. Maji, Sudhanshu Singh, Subhasis Mandal, Sukanta K. Sarangi, B. K. Bandyopadhyay, A. R. Bal, D. K. Sharma, S. L. Krishnamurthy, H.N. Singh, A. S. delos Reyes, D. Villanueva, T. Paris, U. S. Singh, S. M. Haefele, Abdelbagi M. Ismail **Participatory evaluation guides the development and selection of farmers' preferred rice varieties for salt- and flood-affected coastal deltas of South and Southeast Asia** *Field Crops Research (2017): 11 p.* doi:10.1016/j.fcr.2017.03.009

Butardo, Vito M., Roslen Anacleto, Sabiha Parween, Irene Samson, Krishna de Guzman, Crisline Mae Alhambra, Gopal Misra, and Nese Sreenivasulu **Systems genetics identifies a novel regulatory domain of amylose synthesis** *Plant Physiology 173 (2017): 887-906.* doi:10.1104/pp.16.01248

Calingacion, Mariafe, Roland Mumm, Kevin Tan, Lenie Quiatchon-Baeza, Jeanaflor C. Concepcion, Jos A. Hageman, Sangeeta Prakash, Melissa Fitzgerald and Robert D. Hall **A multidisciplinary phenotyping and genotyping analysis of a mapping population enables quality to be combined with yield in rice** *Frontiers in Molecular Biosciences 4, no. 32 (2017): 1-16.* doi:10.3389/fmolb.2017.00032

Chaipanya, Chaivarakun, Mary Jeanie Telebanco-Yanoria, Berlaine Quime, Apinya Longya, Siripar Korinsak, Siriporn Korinsak, Theerayut Toojinda, Apichart Vanavichit, Chatchawan Jantasuriyarat, and Bo Zhou **Dissection of broad-spectrum resistance of the Thai rice variety Jao Hom Nin conferred by two resistance genes against rice blast***Rice 10, no. 18 (2017): 11 p.* doi:10.1186/s12284-017-0159-0

Demont, Matty, and Pieter Rutsaert **Restructuring the Vietnamese rice sector: towards increasing sustainability** *Sustainability 9, no. 325 (2017): 15 p.* doi:10.3390/su9020325

Dilla-Ermita Christine Jade, Erwin Tandayu, Venice Margarette Juanillas, Jeffrey Detras, Dennis Nicuh Lozada, Maria Stefanie Dwiyanti, Casiana Vera Cruz, Edwige Gaby Nkouaya Mbanjo, Edna Ardales, Maria Genaleen Diaz, Merlyn Mendioro, Michael J. Thomson, and Tobias Kretzschmar **Genome-wide association analysis tracks bacterial leaf blight resistance loci in rice diverse germplasm** *Rice 10, no. 8 (2017): 17 p.* doi:10.1186/s12284-017-0147-4

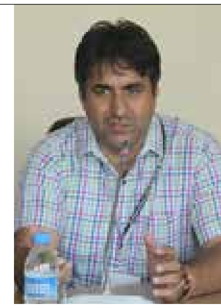
Furuta, Tomoyuki, Motoyuki Ashikari, Kshirod K. Jena, Kazuyuki Doi, and Stefan Reuscher **Adapting genotyping-by-sequencing for rice F2 populations** *G3: Genes|Genomes|Genetics 7 (2017): 881-893.* doi:10.1534/g3.116.038190

Hay, Fiona R., and Katherine J. Whitehouse. **Rethinking the approach to viability monitoring in seed genebanks** *Conservation Physiology 5, no. 1 (2017): cox009 (13p.).* doi:10.1093/conphys/cox009

Iqbal, Noushina, Nafees A. Khan, Antonio Ferrante, Alice Trivellini, Alessandra Francini, M. Iqbal R. Khan **Ethylene role in plant growth, development and senescence: interaction with other phytohormones** *Frontiers in Plant Science 8, no. 475 (2017): 1-19.* doi:10.3389/fpls.2017.00475

Jeong, K. H.; A. Baten, D. L. E. Waters, O. Pantoja, C. J. Julia, M. Wissuwa, S. Heuer, T. Kretzschmar, and T. J. Rose **Phosphorus remobilization from rice flag leaves during grain filling: an RNA-seq study** *Plant Biotechnology Journal 15 (2017): 15-26.* doi:10.1111/pbi.12586

Science and technology: helping to satisfy the food needs of every individual



by Manzoor **Dar** and Showkat **Waza**

The resource-poor farmers residing in stress-prone areas form the section of our society that is highly vulnerable to poverty and hunger. Environmental stresses such as drought, flood, and salinity frequently destroy their food crops, forcing them to leave their agricultural fields fallow. These environmental conditions affect the poorest farmers—women, children, and the elderly in particular—disproportionately, causing them to eat less, withdraw their children from school, migrate for employment, and sell assets to meet immediate needs. They frequently face chronic hunger, malnutrition, and poor health, and they lack the resilience to cope with economic setbacks and natural disasters. Moreover, recurring environmental stresses reduce the propensity of farmers to adopt new and profitable technologies, thus further increasing their vulnerability and decreasing their capability to overcome hunger and poverty.

Investments, innovations, and empowering the world's most vulnerable populations are needed to obtain a global food system that adapts to climate change without disturbing the sustainability of our natural resource base. The present global need is to cope with the menace of environmental stresses so that everyone has reliable access to a sufficient quantity, quality, and diversity of food.

However, no single strategy can help us to solve this problem.

Proven technologies, policies, and institutional resources need to be collectively adopted to ensure the mitigation of stress-driven shocks at different levels. Integrated strategies that include agricultural technologies for environmental stress management such as climate-resilient crops and varieties, crop management practices, weather forecasting and information communication, weather-index insurance systems, market development, and price information can help to manage environmental stresses. Additionally, there is a strong need to innovate the current agricultural extension system and increase access to information related to food production in stress-prone areas.

Science and technology need to play an essential role in moving the globe into a safe operating space where agriculture can satisfy the food needs of every individual

Science and technology need to play an essential role in moving the globe into a safe operating space where agriculture can satisfy the food needs of every individual, especially those living in agriculturally marginal ecosystems. The present scenario in stress-prone areas requires major innovations to transform the current patterns of food production, distribution, and consumption. Farmers will have to produce a substantially larger amount of food on less land with less water, energy, fertilizer, and pesticides without disturbing ecosystems. The scientific community is expected to play an important role in obtaining strategic investments to set up resilient agricultural production systems, reduce greenhouse gas emissions, safeguard adequate nutrition, and further develop a global knowledge system for sustainability.

Larger investments for the sustainability of agriculture in stress-prone areas form the essential component of long-term economic development. The sooner these investments are accomplished, the greater the expected gains.

The International Rice Research Institute (IRRI) has been investing in science, technology, and innovations that can render large-scale benefits for resource-poor farmers. Scientific efforts by IRRI have contributed substantially over two Green Revolutions to relieve hunger and poverty in Asia. The science, technology, and innovations involved in the second Green Revolution are mainly meant for resource-poor farmers and aim to leave no farmer behind.

A third Green Revolution is envisaged to commence around 2030, when farmers will start planting yield-plateau-breaking C_4 and nitrogen-fixing rice varieties. These varieties will be inordinately eco-friendly and require only half the amount of water and nitrogen currently used in rice production.

Thus, high science, technology, and innovations by scientists and policymakers can help the world's poor to overcome poverty and hunger more rapidly and efficiently. ■

Dr. Dar is a development specialist in agricultural research at IRRI-India. Dr. Waza is a postdoctoral researcher at IRRI-India.

The role of science, technology, and innovation in reducing poverty and hunger

by Karen Ann-Kuenzel **Moldenhauer**

Years ago, while I was attending graduate school at Iowa State University, Dr. Kenneth Frey challenged each of us to write a paper for his advanced plant breeding course on what we thought would make the biggest contribution to plant breeding in the future. I selected computers, and little did I know in the late 1970s how much this technology would shape and influence the future of science in general.

I know that computers have not only greatly influenced plant breeding and science today, but our whole world and our world view as well. Numerous techniques have been and are constantly being developed in the areas of plant breeding and it is impossible to keep up with all of them and still accomplish something. A technology revolution is occurring and, to paraphrase what others have said, the world of scientific knowledge is growing so fast and we, as scientists, are becoming more and more specialized and carving out our own areas of expertise, allowing us to thoroughly understand only a small part of what is happening around us.

Bearing this in mind, innovations are occurring in all areas of science and, like the industrial revolution in the early 1800s that saved the world from the fate of the Malthusian trap, many of today's advances will allow us to break free of poverty and hunger. These advances give scientists and others the ability to increase the production of food, livestock feed, and fiber as well as create networks and the means to oversee the dissemination of the products to vulnerable populations.

In today's world, information travels at a tremendous pace. We know instantly when there is an earthquake, flood, landslide, terrorist attack, act of war, etc. With the widespread use of open-access journals, scientific literature is available to everyone. And, with the many organizations such as the CGIAR centers, Food and Agriculture Organization of the United Nations, and International Atomic Energy Agency, which are located around the world working within countries, science is called into action to help those in underdeveloped and developing countries.

Innovations are occurring in all areas of science and, like the industrial revolution in the early 1800s that saved the world from the fate of the Malthusian trap, many of today's advances will allow us to break free of poverty and hunger.

The rapidly emerging understanding of genetics, genome manipulating techniques, and the ability to tailor major food crops to contain important nutrients in the future will allow molecular geneticists and plant breeders to provide an increasing food supply. The products of new technologies such as CRISPR, which edits genes and is considered as nontransgenic by some, have the potential to create a whole spectrum of improved germplasm, including such traits as tolerance of adverse environmental conditions.

The use of drones to collect phenotypic data will increase at an exponential rate in the future, providing additional information for researchers. Huge phenotypic and genomic datasets can now be mined through bioinformatics. I envision a future in which plant breeders will be able to take a device similar to a Star Trek "tricorder" to the field and sample plants in an F_2 population, identifying those that have a specified set of genes that are preloaded in the instrument, eliminating the need to take samples into the laboratory. Another future possibility is the ability to sequence plants right in the field.

These and other advances will provide plant breeders and other scientists with the opportunity to make rapid discoveries that could reduce poverty and hunger in vulnerable populations. ■

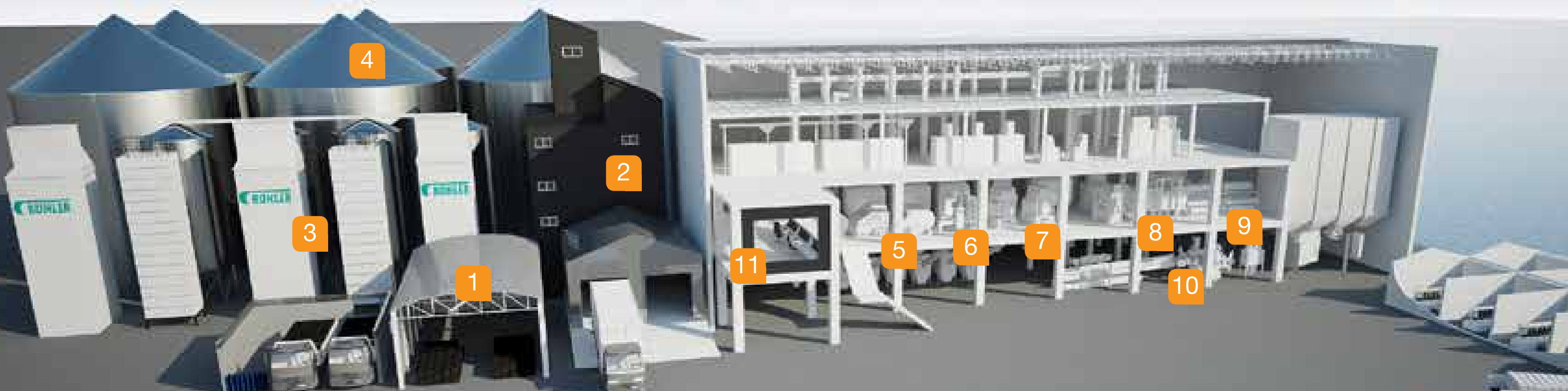
Dr. Moldenhauer is a professor of Crops, Soils, and Environmental Sciences at the University of Arkansas and a holder of the Rice Industry Chair for Variety Development. She is also a member of the International Rice Research Institute's Board of Trustees.

The number one **partner of choice** for rice processors worldwide.

Present in over 140 countries, our global reach gives rice processors unparalleled access to a wide range of capabilities including a comprehensive machine portfolio, supported by our turnkey capabilities - successfully delivering equipment, service and support locally.

Got a question? Let's talk about it.

rice.processing@buhlergroup.com, www.buhlergroup.com/rice



12 Additional services

- Engineering, technology and project management
- Research and development support
- Processing of by-products
- Education and training programs
- Local on-site services

1. Paddy reception and handling
2. Pre-cleaning
3. Paddy drying systems
4. Paddy storage systems
5. Cleaning
6. Hulling
7. Whitening and polishing
8. Grading
9. Optical sorting
10. Weighing, dosifying and bagging
11. Automation systems
12. Additional services

Innovations for a **better world.**

BÜHLER