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Networking a Pivotal Strategy for Rice Genetic Improvement

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Abstract

Network approach for boosting efficiency in agricultural research has been widely accepted by various International and National research organizations, because of the wide-ranging benefits, most important of which is the acceleration of transfer of technology to the farmer. The International Network for Genetic Evaluation of Rice (INGER), the subject of this paper, is the world's largest agricultural research network participated by more than 75 countries in Asia, Africa, Latin America, the Caribbean and the Oceania. Through the cooperative exchange and evaluation of promising breeding lines, by end of 2015 a total of 1,120 INGER-tested lines were directly released as varieties to farmers in 74 countries. Further, several entries were used in crosses as genetic donors for important traits, and 1,129 elite lines from those progenies were released as varieties in 21 countries. Some entries have been successfully utilized as restorers in hybrid rice programs. For example, 36 hybrids released in India and 34 in China, owe their restorer source to INGER. The multi-location screening trials have provided valuable information on pathogenic variation in major disease causing organisms, and biotype variation in severe crop-damaging insect pests. Various aspects of interaction of rice with weather variables have been elucidated through special studies conducted at 23 INGER test sites in 16 countries. INGER now is at crossroads; some directions it has to pursue have been indicated for it to sustain its relevance to the national programs, and effectively address the emerging needs.

Introduction

Rice, the world's foremost food crop derived from a wild progenitor was born as a semi-aquatic plant in the hot humid tropics with a strong monsoonal pattern. However, it has gradually forayed into a diversity of habitats, breaking the environmental, as well as geographical barriers, and encompassing agroecosystems that reflect a wide range of water and temperature regimes, altitude levels and edaphic properties. Its cultivation extends to latitudes that circumscribe the tropical and semitemperate environments, ranging from 40^0 south in central Argentina to 51^0 north in northeastern China. Thus, rice is grown in more diverse environmental conditions than any other major crop. The flip side of such an ecological sprawl is its face-off with a plethora of biotic and abiotic stresses, posing a strong challenge for rice genetic improvement.

Prior to the Green Revolution era, rice scientists in the developing countries used to work in scientific isolation with limited experimental materials, paucity of research facilities including literature, inadequate training, and lack of opportunities to interact with fellow rice scientists at other locations. Moreover, the experimental stations in several instances were not quite representative of the ecosystems they were purported to serve. Progress in rice yields and thereby its production, thus remained at a pace that allowed it to be overrun by the rate of population growth. That was the post-world war II scenario in several developing countries, where rice is the main staple, and that situation has raised concerns and awareness at both national and international levels.

Because of the geographical and ecological diversity, a structured networking of rice breeding programs across the world is strategically vital for global genetic improvement of rice for cultivation in different ecosystems, and raising the world output of the grain. Such an approach is also effective within national programs with wide-ranging rice cultural systems. Networks are inexpensive and at the same time are effective catalysts for research. Collaborative networks help spread useful research results among regions with similar agroecologies.

Some national programs that gained experience in rice research turned towards pooling up their resources for a nationwide cooperative crop improvement program. An excellent example is the All India Coordinated Rice Improvement Project (AICRIP), a largest national rice research network, established by the Indian Council of Agricultural Research (ICAR) in 1965. AICRIP has successfully brought together scientists working at over 100 research stations across different states, and through its exchange platform, forged national cooperation on research on genetic enhancement, nutrition management, and protection against major insects and pathogens.

Shastry (1971) summarized the concepts, organization and implementation of the AICRIP program. AICRIP is one of the several nationwide networks launched by ICAR during the sixties, very thoughtfully, with focus on crops, fish, dairy and poultry.

Historically, at an international level, a limited and informal exchange of plant germplasm among scientists from few countries with common interest took place prior to World War II. The International Wheat Stem Rust Nursery established by the United States Department of Agriculture (USDA) in 1950 was the first formal and systematic nursery to transcend the national borders. This was necessitated by a serious outbreak of a new race of the stem rust in 1950's (Plucknett and Smith, 1984). The Rice Blast Nursery organized by IRRI in 1963, and the Spring Wheat Yield Nursery organized by the International Maize and Wheat Improvement Center (CIMMYT) in 1964 represent the first efforts by the International Agricultural Research Centres (IARCs) to work cooperatively with the National Agricultural and Extension Systems (NARES).

The establishment of a series of IARCs under the aegis of the Consultative Group of International Agricultural Research Centers (CGIAR) was a quintessential response to the emerging food crisis in early sixties of last century in the developing world. The first among those was the International Rice Research Institute (IRRI), originally funded by the Rockefeller and Ford Foundations, and established in the Philippines in 1960. IRRI in its first decade primarily focused on research and related activities at its own center, which resulted among other things in the development of a high-yielding semi-dwarf variety, IR8 (IRRI's flagship); establishment of a gene bank; development of screening techniques for resistance to major diseases and insects; establishment of a comprehensive training program, setting up of a library with world's largest collection of rice literature, and so on. To buttress the Varietal Improvement research, a multidisciplinary 'Genetic Evaluation and Utilization (GEU)' program was introduced in IRRI's second decade. Once equipped with the necessary research wherewithal, and having acquired the capacity to take a lead role, IRRI initiated the establishment of various research networks with the cooperation and commitment of the NARES. The International Rice Testing Program (IRTP) was the first among those networks. Initiation of the networks also reflects the concern and realization of IRRI, that while it has a mandate for rice improvement across the rice-growing world, its research facilities are located in but one of the several rice growing environments. For example, gall midge, a major insect pest in parts of South Asia does not occur in the Philippines, which limits IRRI's capabilities to carry research related to that pest without collaboration with scientists in the concerned national programs. Similar is the case with problems such as deepwater, low temperature *etc.* Thus networking involving NARES has become imperative for global rice improvement.

The author had the privilege to be associated with AICRIP for over 10 years and with the International Network for Genetic Evaluation of Rice (INGER, initially known as IRTP) for nearly 20 years. The experiences gained at AICRIP, the world's largest national rice improvement network proved to be of immense help to him in the implementation of INGER. To demonstrate the benefits of networking for rice breeding research, the procedures and impact of INGER have been chosen as the subject of this paper, because of its global nature.

Networking types and concepts

Cooperation through research networking has been widely adapted by various International Agricultural Research Centers in view of the wide-ranging benefits accrued by that approach. Contributions of spillover effects from regions where research is conducted to other regions with similar agroecologies has been determined to be substantial (Davis *et al.,* 1986). There are various types of networks, the design and formulations of which depend on the purpose and goals of the specified cooperative effort. Cummings and Martin (1986) proposed three types of networks:1) Information Networks that collate and disseminate research information to individuals on the mailing list, 2) Scientific Consultation Networks to share research information and ideas through discussions in meetings and workshops, and 3) Collaborative Research Networks involving joint planning and execution of research of common interest. Plucknett and Smith (1984) considered an addition of a fourth type, namely, the Material Exchange Network concerned with testing of varieties, machinery *etc.* However, in classifying the International Nurseries as typified by INGER, the author wishes to elaborate the Material Exchange Network as 'Material and Methodologies Exchange Network', where the evaluation procedures are jointly planned.

Plucknett and Smith (1984) outlined seven principles on which successful networks are grounded.

These are: Clearly defined problem and realistic research agenda; widely shared problem; strong self-interest; willingness of participants to commit resources; availability of outside funding; sufficient training and expertise of the participants to be able to make useful contributions; and a strong and efficient leadership to win the confidence of the participants. The author considers three additional requirements of importance: establishment of various mechanisms for interaction among the participants; unrestricted exchange of research materials and information; and treating the network trials as an integral part of the respective local research programs, instead of viewing them as separate and parallel entities.

International Network for Genetic Evaluation of Rice (INGER)

INGER framework

International Rice testing program (IRTP) was established by IRRI in 1975 with generous funding from the United Nations Development Program (UNDP).The network has been subsequently renamed by the author as 'International Network for Genetic Evaluation of Rice' (INGER) to better reflect the purpose and goals of the program. This cooperative program was initially implemented in Asia and later extended to rice-growing countries in Africa, Latin America and the Caribbean in cooperation with the international centers located in those respective regions, namely, International Institute of Tropical Agriculture (IITA), Africa Rice Center (formerly known as WARDA) and International Center for Tropical Agriculture (CIAT). The program which started with 12 Asian countries gradually expanded to more than 75 countries across the rice-growing world, and involves the participation of over 600 rice research stations and more than 1500 rice scientists of various disciplines – breeders, pathologists, entomologists, soil scientists, physiologists and agronomists. Thus the network reflects an international multidisciplinary approach to rice varietal improvement. Individual experimental stations assume financial responsibility for the conduct of trials at their respective locations, whereas IRRI defrays the costs involved in the logistics of processing and dispatch of seed; data analysis and preparation and distribution of reports; and in the organization of training programs, workshops and joint site visits. The coordinator located at IRRI assumes global responsibility for implementation of INGER, whereas the regional coordinators located at the respective international centers, plan the testing and evaluation in those specific regions. An advisory committee representing experienced rice scientists from selected countries meets annually to review the progress of INGER and provide suggestions to promote and sustain the relevance of the network to the national needs.

INGER objectives:

- To make the elite rice germplasm available to all rice scientists across the rice-growing world for direct use after proper evaluation, or for use in crosses as parental material.
- To provide rice scientists from the participating countries with an opportunity to assess their own advanced breeding lines over a wide range of climatic, cultural, soil, and pest and disease conditions.
- To identify genetic sources for resistance to major biotic stresses and tolerance for abiotic stresses.
- To monitor and evaluate the variation in pathogen strains and insect biotypes.
- To promote interaction and cooperation among worldwide rice improvement scientists.
- To serve as a Center for information exchange on how varietal characteristics interact with diverse rice growing environments.
- To accelerate the transfer of technology to the farmer.

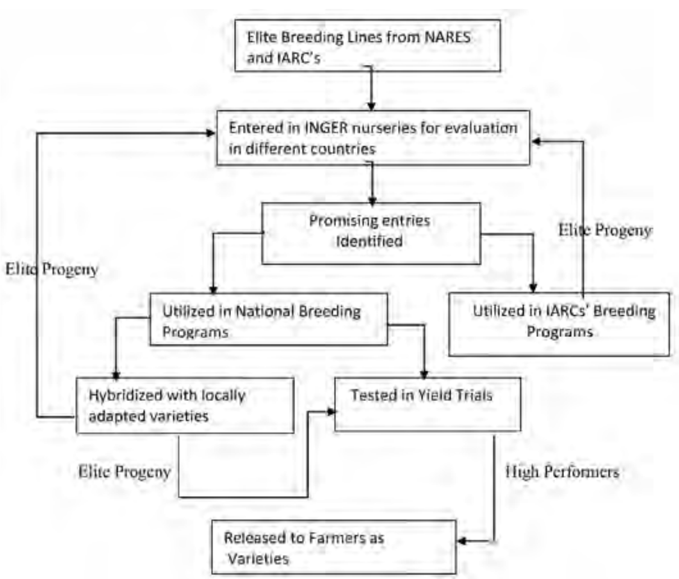
The network addresses sustainability by 1) promoting genetic diversity in rice to reduce vulnerability to pest epidemics through exchanging a broad pool of genetic material, 2) identifying a range of genetic sources for durable resistance to diseases and insects that help lessen the use of chemicals, and 3) identifying genotypes with stable yields under rainfed and other unfavorable environments.

INGER logistics / procedures

Small quantities of seed of promising breeding lines from various NARES and International Centers (mainly IRRI) are obtained by the INGER Coordinator and multiplied at IRRI experimental farm to raise a required quantity of seed for experimentation at various cooperating stations. Obtaining small quantities for multiplication has been necessitated by two factors, 1) Breeders' seed of promising lines from various centers is generally limited in quantity, and may not be enough for multi-location testing, and 2) more importantly, seed increase at IRRI farm provides an opportunity to examine and ensure the seed quality in terms of both genetic purity and seed health, which in turn assures the reliability of test results. At the time of receipt of nominations and prior to distribution of nurseries, the seed is subjected to rigorous phytosanitary treatments to prevent the transfer of diseases and insect pests to the cooperating countries, and to retain the seed vigor during shipping to the test sites. The relevant phytosanitary certificate is enclosed in the seed boxes.

The pooled promising breeding lines and varieties from NARES and IARCs are organized into various types of nurseries primarily with focus on different ecosystems (irrigated, rainfed upland, rainfed lowland, tidal wetlands, deepwater *etc.*), and on different biotic and abiotic stresses. The ecosystem-oriented category involves both yield trials and observational nurseries. New nurseries have been added recently to address current issues like climate change. When the program started in 1975, over 80% of the test entries came from IRRI and the remaining from the NARES. In course of ten years after the start, the proportion of contribution of entries has significantly changed, with over 65% entries originating from NARES and 35% from IARCs, primarily from IRRI. This reflects on the strengthening of the national breeding programs, as resulting from active participation of its scientists in INGER, and in the network-sponsored joint site visits, workshops and training programs, with an opportunity to interact with fellow rice scientists from other countries. Thus, with the strengthening of capabilities and institution building, the breeding researches of the NARES progressed from dependency to interdependency. NARES materials get fingerprinted to alleviate their concerns relating to intellectual property rights. A flowchart of international cooperative exchange and genetic evaluation of promising rice breeding lines through INGER is shown in Figure 1. Through that mechanism, over the past four decades, nearly three million seed samples representing around 55,500 entries of advanced lines have been shared for evaluation by hundreds of rice scientists at more than 600 research stations in 85 countries (Rice Today, 2015).

A Standard Evaluation System (SES) has been developed for the INGER nurseries to facilitate scoring of the morphological and physiological traits, and assessing the degree of damage caused by the major insects and pathogens. SES promotes uniform methodology in data collection lending comparability of test results from various network centers, and thus facilitating valid interpretation of the multi-location results. Specially designed field books are sent with the seed to secure a uniform reporting procedure. Data from different test sites are computerized, processed and stored for retrieval as and when needed. Results from the nurseries are analyzed by location, country and region, and across locations and years. Reports of the multi-location results with analyses are published annually and distributed to all the cooperators for follow-up research and extension activities. More recently an INGER website has been developed from which users can download reports, submit trial data and request nurseries and breeding lines.



NARES: National Agricultural Research and Extension Systems

IARCs: International Agricultural Research Centers

Figure 1: INGER Cooperative Rice Breeding Flow Chart

Monitoring visits are organized annually for a joint review of the INGER trials at selected sites by a group of scientists from NARES and IARCs. These reviews provide useful feedback for appropriate follow-up research. Also, the joint site visits along with the INGER advisory committee meetings mentioned above, and the periodic INGER and IRRI sponsored workshops provide excellent forums for interaction among rice breeders from different countries and organizations. For younger scientists they also serve as training avenues.

INGER utilization and impact

Over the past four decades, nearly three million seed samples representing around 55,500 entries of advanced lines have been shared for evaluation at more than 600 research stations in 85 countries. By end of 2015, a total of 1,120 INGER tested lines have been directly released as varieties to farmers in 74 countries in Asia, Africa, Latin America and the Caribbean for culture in different ecosystems. This signifies a true international cooperation, because several of those varieties were bred in one country and made available to farmers in another country. Further, cooperators from 51 countries made more than 20,000 crosses using genetic donors from 68 countries for incorporating various important traits, and 1,129 derivatives from those crosses were released as varieties in 21 countries (Rice Today, 2015). Some promising INGER lines have been successfully used as restorers in hybrid rice programs. For example, 34 hybrids released in China and 36 hybrids released in India to date have been developed utilizing entries from INGER.

Countries, big and small, irrespective of degree of development have been equally benefited by participation in INGER, while the network served as a two-directional conduit for those countries with greater experience in rice breeding research. According to the director of the Indian Rice Research Institute (IIRR), Hyderabad, V. Ravindra Babu, “In India, 43% of varietal releases (about 70 varieties) were directly introduced by INGER, while 250 varieties with INGER-derived parents have been released in 24 Indian states. In reciprocation, 35 Indian rice lines were released as 46 varieties in 28 countries”. Shinhua Cheng, director-general of China National Rice Research Institute says “From 1981 to 2012, around 16.6 million hectares were cumulatively planted with INGER materials. These have resulted in the harvest of 6.2 million more tons of rough rice with an economic benefit of around USD 530 million. At least 2500 INGER entries were used as parents, restorers, and/or disease and pest-resistant donors in national and regional rice breeding programs. On the other hand, around 560 outstanding Chinese rice varieties have been nominated to INGER over the years for global evaluation and use in other countries” (Rice Today, 2015). According to Edgar Torres, head of the Rice Breeding Program at CIAT, “INGER has been a cornerstone for the development of rice varieties in Latin America and the Caribbean (LAC). Since 1976, this network has been effective in disseminating improved materials. Around 115 rice varieties released in LAC originated from elite INGER lines. This germplasm also provided valuable donors for blast resistance and cold tolerance, among other key traits" (Rice Today, 2015). INGER's impact is even more pronounced in smaller and newer breeding programs according to Glen Gregorio, former IRRI plant breeder. According to him, varietal releases directly or indirectly traceable to INGER are 73% for Nepal, 72% for Myanmar, 61% for Indonesia, and 51% for Cambodia. Fifteen INGER-introduced entries were released to farmers in seven African countries: Benin. Burundi, Kenya, Mozambique, Malawi, Uganda and Zambia. Thus INGER had an impact on rice production in rice-growing countries around the world.

Apart from enabling identification of elite varieties and genetic donors for important traits, multi-location network of yield trials provide an excellent opportunity for studying Genotype by Environment (G x E) interactions of rice. When combined with data from over years, a time factor is added and a good continuum of multi-environmental variable data points are obtained to draw valid conclusions. For example, multi-location INGER rainfed lowland variety trials helped in identifying breeding lines with stable performance under rainfed culture. Figure 2 shows that the line BR 850-9-1 performed well under a wide range of environmental stresses related to rainfed culture, whereas the line BR 51-282-8 in the same set of trials gave higher yields only under favorable conditions (Seshu, 1986). Such useful information from just two or three seasons, would not have been possible, if the breeder concerned works in isolation at his/her own research station. Phenotypic stability of performance of the variety, Jaya, in irrigated yield trials was similarly determined through national multi-location trials of AICRIP in India (Seshu *et al*, 1974).

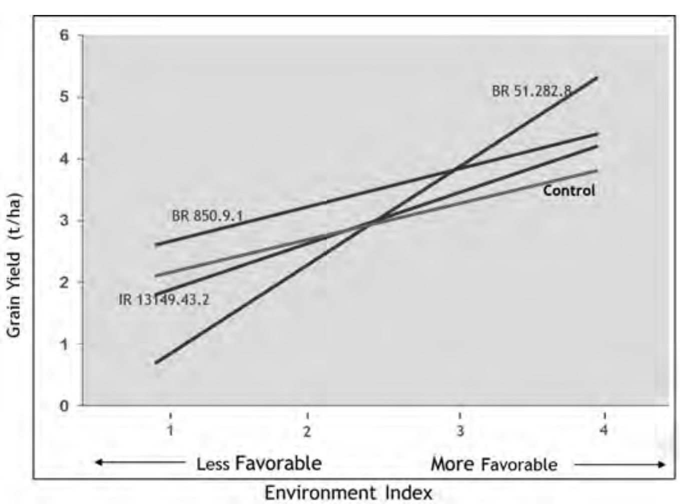


Figure 2: An example of utilization of multi-location Network Data-BR 850-9-1 shows a stable performance across a range of rainfed condition

In another G x E study, the response of rice to solar radiation and temperature was estimated from international irrigated rice variety trials conducted in 40 environments during 1976-1981 (Seshu and Cady, 1984). Both high and low levels of crop production could be explained by major weather factors. Figure 3 displays an isoquant plot for equal predicted yields (t/ha) for combinations of minimum temperature and solar radiation during ripening (30-day period after flowering). A significant negative correlation was evident between the mean temperature during the ripening stage and grain yield. In yet another study, through a special grant from UNDP, a nursery designated as International Rice-Weather Yield Nursery (IRWYN) was established and evaluated at 23 selected INGER sites in 16 countries representing a wide range of levels of temperature and solar radiation (Oldeman *et al*, 1987). That study yielded valuable information on the impact of major weather variables on the growth and yield of rice. Despite several studies in the past, it was difficult to find in the literature, estimates of rice-environment relationships with acceptably small standard errors based on field plot data, because of limited number and distribution of weather data points, and lack of time variables. INGER alleviated the problems by gathering data from a network of experiments over locations and years and thereby providing valid research information.

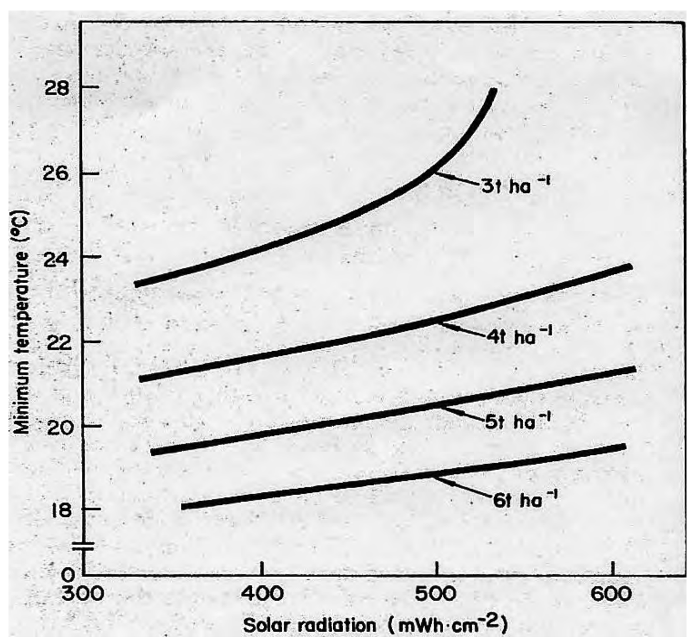


Figure 3: Isoquant plot for equal predicted yield for combinations of minimum temperature and solar radiation during ripening

Like with physical environment, INGER capitalized on the network approach in determining the G x E interaction in respect of biological environment. First, the variations within the disease causing organisms (pathogenic races/strains), and within the damage causing insect pests (biotypes) were evaluated through differential reactions of common set of varieties across the screening sites. Following that, the genotypic responses to such variation patterns are determined under both field and greenhouse conditions. Significant information through INGER screening nurseries was obtained on pathogenic variation in the major disease causing organisms such as blast (Seshu and Kauffman, 1980) and bacterial leaf blight (Seshu, 1989); and on biotype variation in major insect pests such as rice gallmidge (Heinrichs and Seshu, 1981) and brown planthopper (Seshu and Kauffman, 1980). Sources of genetic resistance to major diseases and insects (both broad spectrum and location-specific) have been identified from the respective nurseries. For example, PTB 33 has been found to be resistant to all identified biotypes of the brown planthopper, and in all screening tests in Asia. Likewise, IR54 and RP633-76-1 showed resistance to bacterial leaf blight over several locations in Asia. The information on pathogenic and biotype variation was successfully utilized in various national breeding programs in choosing the location-specific genetic donors for resistance to relevant insects and diseases. Regional variations have become evident in respect of varietal reactions to some of the diseases and pests. As shown in Figure 4, variation was evident in the Brown Planthopper nursery in respect of percentage of entries susceptible to that insect among different regions of Asia (Seshu and Kauffman, 1980), with higher proportion of susceptible entries occurring at sites in South Asia.

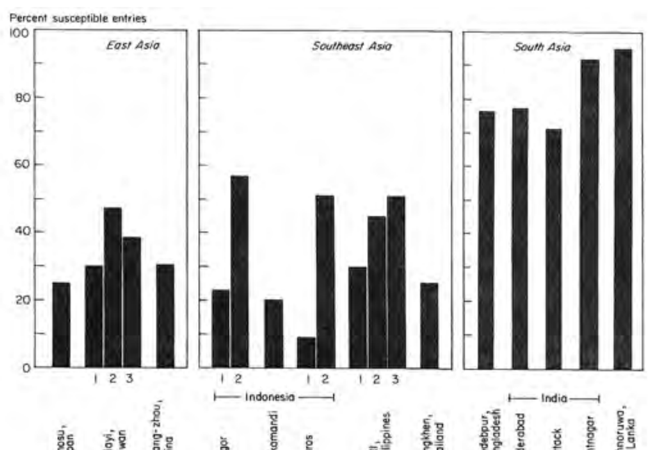


Figure 4: Percent susceptible entries at different test sites of International brown planthopper Nursery by regions of Asia (1, 2 and 3 refer to biotypes of BPH) (Seshu & Kaufmann, 1980)

Similar regional variation in Asia was observed in respect of reaction of entries to bacterial leaf blight (BLB), as evident from the results of the BLB nursery over years (Figure 5). A higher percentage of entries were found to be susceptible in South Asia, as compared to those in East and Southeast Asia, indicating possibly a higher degree of virulence of the pathogenic strains of BLB in South Asia.

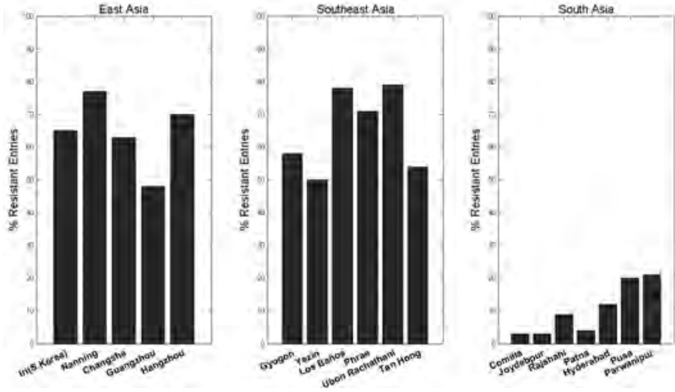


Figure 5: Region-wise variation in severity of bacterial blight strains in Asia as reflected by the percentage of resistant entries in Bacterial Blight Screening Nursery (Seshu, 1986)

The above are but few examples of the benefits accruing from multi-location cooperative networking for efficient and sustainable genetic improvement with savings on both time and costs.

From 1975, when INGER was established to 2015, the global rice production increased by about 30% (Source: Statista), whereas the acreage during that period increased by only 12%. The major contribution for the increase is from the improved varieties. INGER-tested and released varieties caused a significant part of that increase, as indicated by the number of varieties released through that mechanism. Yale University professors (Robert Evenson and Douglas Gollin) studied 591 INGER-derived high-yielding and pest-resistant varieties released in 64 countries. They estimated that each released variety contributes annually USD 2.5 million to the global economy at 1990's costs. Using that old figure on current data, the 1,120 INGER test lines released as varieties contributes annually USD 2.8 billion to the world economy.

Some comments by different organizations that reviewed INGER (IRTP)

IFDC: The International Rice Testing Program (IRTP) is well known with national agricultural research programs and has been very successful in providing genetic material for local breeding programs and as a forum for exchanging information on breeding methods and priorities.

ISNAR: The International Rice Testing Program (IRTP) has been widely recognized as one of the more successful research efforts of the IRRI scientists. Its impact has been enormous.

ICRISAT: The International Rice Testing and Improvement Program (IRTP) of the International Rice Research Institute is regarded as an excellent example of an inter-institutional, multidisciplinary approach for increasing rice yields in several countries in the developing world.

World Bank: International Rice Testing Program has made identifiable contributions to rice cultivation throughout the world.

Rockefeller Foundation: The International testing of rice varieties by national researchers under the conditions prevailing in their own research stations has probably been the single most effective dimension of IRRI's rice improvement work.

USAID: It is a project of the highest priority and worldwide importance.

CIDA: It is a corner-stone of IRRI's international network of rice scientists and the means whereby 'new' rice varieties are tested for their location-specificity, with improved varieties identified for specific environmental conditions.

UNDP Natural Resources Division: The network established has significantly increased agricultural productivity and furthered technical cooperation in adoption of rice improvement techniques.

Current Science (1986), Vol.55(9): 477-478: The major achievement of IRRI over the past two decades is in organizing and implementing large scale international testing of rice strains in different ecosystems. These studies involve extraordinary leadership qualities to work in close collaboration with scientists of different nations and cultural backgrounds. The achievements in this regard are highly commendable.

CGIAR / TAC External Review of IRRI, 1992. Assessment of IRTP / INGER: IRTP today is the largest single pathway for distributing, exchanging, and testing new rice varieties and breeding lines, worldwide. A large amount of valuable information has been gathered through IRTP on biotype and race differences among major pests and pathogens, on location-specific resistance genes, and on interaction of rice and major weather factors, which helped in the construction of simulation models. IRTP has allowed international seed exchange to be made unhampered by political restrictions. This major achievement together with the joint monitoring site visits involving NARS and IARC scientists, are services that are highly valued by the NARES. It is the panel's view that IRTP (INGER), with its sharp focus on germplasm and environmental characterization, has brought a great level of effectiveness in IRRI's germplasm exchange and evaluation activities. IRTP has made the germplasm exchange and evaluation activities more demand-driven, and less supply-driven.

Philippines Social Scientist: According to Gelia Castillo, a noted social scientist (designated as Philippine National Scientist), rice seeds share a common food value and speak a common language that transcends politics, geography, and culture. In Africa, for instance, INGER helped break a barrier in rice science between English and French-speaking countries. She maintains that "INGER is a beautiful illustration of humanity working together for our common future in a world filled with social conflicts, tribal wars, and fierce competition over the control of natural resources" (Rice Today, 2015).

Moving ahead with INGER

INGER has been established over a period of time as a strong cooperative platform for rice genetic improvement through the concerted efforts of the world community of rice scientists, breaking down social, cultural and political barriers. Every effort should be made to maintain and nurture such a well-proven excellent mechanism through both technical prowess and financial sustainability in order to uphold and validate the prodigious efforts that have gone into its establishment. In the larger interests of the world's food security, the research institutions concerned and the funding agencies should take cognizance of the need to enable INGER maintain its dynamism in addressing effectively the changing needs of rice improvement. The cooperative structure so carefully crafted should be efficiently utilized for all future challenges.

Several national programs have gained adequate strength in terms of research capabilities and facilities, and thus are in a position now to share some of the financial and organizational responsibilities to carry forward the successful network program. Delegation and assumption of technical responsibilities should be based on the respective ecosystem advantages with attending stresses. A comprehensive discussion with the concerned NARES will help set the stage for an effective and unhampered continuation of the network to meet the needs arising out of the new challenges.

Presently, as stated above, nurseries are being organized with orientation on important rice cultural ecosystems and on the major stresses encountered by the crop. The sets of nurseries, the composition of individual nurseries, and the type of data collection should reflect on the changing and practical needs of the participating countries. Varietal differences in respect of some important post-harvest traits like seed vigor and threshability should be included in the data collection as they have significant influence on the ultimate yield, and the recorded figures may not reflect on the true yields, if differences exist for those traits.

Shortage of water is probably the single most significant challenge that will confront the world's farmers in the coming years. Rice is a water guzzler when compared to other crops. It uses up to two to three times more water than other food crops such as maize or wheat and consumes around 30% of fresh water used for crops worldwide. Thus there is an urgent need to regulate the water footprints contributed by rice culture. While scientists from relevant disciplines may be pursuing research toward this goal, INGER should do its part by capitalizing on its cooperative base to evaluate varieties at selected representative sites for their performance under a range of hydrological situations. Carefully planned testing should enable identifying varieties performing well with an optimal input of water under irrigated conditions. On the other hand, efforts should be intensified to screen for tolerance to water stress. Also, a systematic monitoring has to be done to elucidate the utilization of several INGER entries identified in the past for drought tolerance, and take stock of the progress made thereof. Promising progenies from those breeding efforts have to be recycled into the INGER system. Issues like climate change have more recently been built into the INGER testing.

When other network trials of relevance to INGER are conducted at a given station (say, cropping systems), it has to be ensured that they are appropriately linked, to derive maximum benefits from the combined information in choosing the more productive location-based varieties.

Finally, it should be noted that increased data-returns from systematically conducted trials underpin the success of the networks. In order for the purpose of establishment of INGER is duly served, the cooperators should also ensure that the data are returned promptly for timely analysis and utilization of the results. Reliability of information from well-conducted trials would accelerate the transfer of new technologies to the farmer, which is our ultimate goal.

Conclusions

Rice has evolved through very high levels of adaptation to various ecological habitats and has its cultivation spread across the continents. Genetic improvement remains a challenge when trying to maintain harmony between rice and its environment. This necessitates active cooperation of scientists within and between the rice growing countries to facilitate pooling and sharing of research materials and expertise through a structured network mechanism. Valuable bonuses from such an approach are savings in time and monetary inputs, and more importantly, acceleration of transfer of technology to the farmer. Pooling of materials from diverse sources also promotes the much needed genetic diversity. While the agro-ecological diversity of rice crop poses a 'challenge' for varietal improvement, the geographical diversity provides an 'opportunity' for cooperation. Individual strengths of the national systems may vary, but their collective strength is formidable. Meaningful fusion of those complementary strengths has powered INGER to effectively serve the needs of the various participating countries in fostering location-specific genetic enhancement of rice. INGER, thus proved to be an epitome of veritable synergy, and signifies the power of cooperation. Networks will continue to play a paramount role in agricultural research. In this context, it is important for the funding agencies to take cognizance of the fact that their financial support to cooperative networks such as INGER would yield very significant returns in terms of world's food security, paling the value of the investment.

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