Gamma Field Symposia

Number 41

OVERSEAS TRENDS IN CROP SCIENCE AND MUTATION BREEDING

2002

INSTITUTE OF RADIATION BREEDING
NIAR MAFF

Ohmiya-machi, Naka-gun, Ibaraki-ken
Japan
OVERSEAS TRENDS IN CROP SCIENCE 
AND MUTATION BREEDING

Report of Symposium 
held on 
July 17-18, 2002

Institute of Radiation Breeding 
NIAS

Ohmiya-machi, Naka-gun, Ibaraki-ken 319-2293 
Japan
General discussion

The lecturers and the members of the Symposium Committee
List of Participants

(41th GF Symposium)

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FOREWORD

Since the 1st symposium was inaugurated in 1962 as a study meeting, a summerschool for researchers in the industrial, academic and public sectors, the symposium has been held consecutively for 41 years. During this period, lecturers spoke on a total of 318 subjects to a total of 5,615 participants, for an average number of 140 participants per session. We express our thanks to the many people who have given us the support we have needed to be able to hold meetings over such a long period of time.

For this session, we asked eight lecturers to give us lectures on the topic “Overseas Trends in Crop Science and Mutation Breeding” Globalization continues to be an active force in various scenes, and agriculture and agricultural products are affected by it every day. Under these circumstances, Japanese crop researchers are active in the international scene and achieve notable results. We believe that learning from their strategies and tactics will give us great courage and hope in pursuing future research.

In a special lecture, Prof. Kohno is scheduled to give us a lecture titled “Crop genetic resource as common human heritage and its utilization” discussing the ideal way of utilizing genetic resources – including his experiences in the cassava breeding developed in the International Tropical Agriculture Research Center (CIAT). Other lecturers were requested to prepare diversified topics about crop breeding in international organizations and in the field of genetic resource research. We consider this a golden opportunity to hear the lectures of those assembled researchers who have been active overseas.

Looking toward the future, both a rapid increase in world population and problems in food supply are expected in the 21st century due to changes in global environments. To preserve global environments and maintain productivity, skillful utilization of those plants that can function to promote environmental purification and recycling is essential, so agriculture is expected to play a role in solving the problems of environments and food supply. To this end, the development of plant species that have new properties will be desired. However, while natural biological resources that have been beneficial to humans continuously decrease, improvements to plants cannot be implemented without the existence of genetic resources as basic materials. In the future, mutation breeding, which allows the creation of genetic resources with new properties, shall undoubtedly become the basic technology for plant improvement.

Furthermore, we would like to introduce to you an additional topic related to the international mutation breeding research; within the scope of atomic cooperation activities in the Asian Region under the financial support from the Japanese Ministry of Education, Culture, Sports, Science and
Technology, mutation breeding is achieving rapid development in eight countries in the Asian Region. The Agricultural Utilization Subcommittee has continued mutation breeding activities over a period of approximately 10 years under the chairmanship of Prof. Shigemitsu Tano, who is present at this meeting.

A database for mutation breeding is maintained among the participating countries, where 150 research institutes are involved, 600 researchers are registered, and the state of research in each country is recorded. These data are going to be published on the homepage of the Japan Atomic Industrial Forum, Inc.

Since we conduct this symposium so that it functions as a place for exchanging research information, both now and in the future, we rely on your further instructions and support.

Lastly, we express our hearty thanks to the lecturers, who kindly made preparations for this symposium by sacrificing their busy schedules, and to related persons who extended cooperation to us.

The Symposium Committee

Shigeki NAGATOMI, Chairperson
Minoru NISHIMURA
Toshikazu MORISHITA
Yuji ITO
Nobuhiro TSUTSUMI
Yasuo NAGATO
Takatoshi TANISAKA
Tetsuro SANADA
Narumi OKA
PROGRAM

Opening address: S. NAGATOMI
Congratulatory address: M. IWABUCHI

Special lecture
Chairperson: Y. SANO
Crop genetic resource as common human heritage and its utilization .................. K. KAWANO

Session I
Chairperson: T. TANISAKA
Rice breeding in the tropical Asia — one of the aspects — ............................. T. IMBE

Session II
Chairperson: R. OHSAWA
Current status of wheat breeding in the developing regions ......................... M. INAGAKI

Session III
Chairperson: Y. EGAWA
Significance of Nutrients Uptake Mechanisms in Cropping Systems ................ J. ARIHARA

Session IV
Chairperson: T. NAGAMINE
Potato breeding with the use of wild genetic resources ............................. K. WATANABE

Session V
Chairperson: T. SUZUKI
Vegetable breeding in China ................................................................. K. SUGIYAMA

Session VI
Chairperson: H. NEMOTO
Rice breeding in west Africa - with special interest in the interspecific
hybridization and Nericas ................................................................. S. TOBITA

Session VII
Chairperson: Y. NAGATO
Rice breeding in Yunnan province and central region by the east
China sea of China ................................................................. Y. KUNIHIRO

Session VIII
Chairperson: K. MARUYAMA
General discussion

Closing address: Y. NAGATO
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CROP GENETIC RESOURCE AS COMMON HUMAN HERITAGE AND ITS UTILIZATION

Kazuo Kawano

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(Formerly, CIAT Asian Cassava Program)

In the “Green Revolution” institutions, namely IRRI (International Rice Research Institute) and CIMMYT (Centro Internacional de Mejoramiento de Maize y Trigo), when their breeding programs were making a dynamic advance in the 1960s, there was a basic understanding that plant genetic resources were part of mankind’s heritage. Agricultural scientists were to effectively utilize this resource for the welfare of all human beings. The CIAT (Centro Internacional de Agricultura Tropical headquartered in Colombia) Cassava Breeding Program was conceived in this tradition in the beginning of the 1970s with an extra social responsibility to deliver technology to the less privileged people in the tropics. The initial decade of this program was mainly dedicated to the collection of germplasm and generation of basic breeding materials. The later decades were devoted to applied breeding in collaboration with international and national programs in Latin America, Asia, and Africa. Fortunately, when this program was set up the governments and national agencies saw the benefits of free germplasm exchange and this was key to the success of the program. The present situation is vastly different with companies attempting to patent genes without knowing their function and various entities restricting the movement of germplasm. In order to counteract the assertion of intellectual property rights by large corporations of the North, movements to grant “farmers’ right” to the genomes of the crop species are spreading among countries in the South. If these protectionist and individual profit seeking policies had existed when the IRRI, CIMMYT and CIAT programs were initiated, they would almost certainly have failed.

I have been involved with all aspects of this CIAT cassava breeding program from its inception to the later stage of delivering the resulting technology. Hence, I am in a unique position to describe the critical biological and social factors that made this program a success. I herein inform a fair and effective case of genetic resource utilization and the related concerns on the abuse of intellectual property right on plant genetic resources.

I. Origins of cultivated plants and their propagation

Almost all the crop species that sustain the lives of today’s world population originated in the
tropics and sub-tropics (Vavilov, 1926; Harlan, 1971). Human ancestors spotted potentially useful plants from wild species and spent thousands of years domesticating and selecting useful cultivars through half-natural, half-artificial breeding (Darwin, 1896; Harlan, 1975). There is no doubt that the genomes of traditional cultivars are the cultural heritage of the farmers in the tropics and sub-tropics.

When we view the world as a contrast between industrialized developed countries and less developed countries, this contrast would nearly automatically correspond to that of temperate countries vs. tropical countries as well as that of countries of abundant food supply vs. countries of struggling agriculture. The presently successful agricultural production in developed countries nearly entirely depends on crop species brought from other areas, mostly from the tropics and sub-tropics. Hence, the contrast between agriculturally developed countries and less developed countries can be seen as a contrast of countries who obtained the crop genetic resources vs. those who supplied them (Table 1). This background notwithstanding, it is the developed countries in the North who are propositioning for the right of obtaining intellectual property rights on genetic materials through patenting, while the genetic resource-rich countries in the South are counteracting by claiming that the genetic resources are primarily their cultural assets.

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II. CIAT Cassava Breeding Program - An Example of Successful Genetic Resource Utilization

II-1. Program focus. The “Green Revolution” that swept across many tropical countries in the late-sixties and seventies provided cheap and reliable supplies of rice and wheat in those countries; the principal beneficiary of this revolution was the vast number of consumers (e.g. David and Otsuka, 1994). From this time on, a strong and persistent criticism of the green revolution was that only those privileged farmers able to irrigate and fertilize their crops abundantly were able to adopt the technology based on high yielding rice and wheat cultivars. Those underprivileged farmers who farmed marginal land without access to irrigation and the ability to use high-input applications were pushed to even more disadvantageous situations (Wharton, 1969; Ruttan, 1977; Lipton and Longhurst, 1989; Shiva, 1991). In the light of these criticisms, the plight of underprivileged tropical farmers became, and has continued to be, a major concern of international agriculture research and development agencies since the seventies. Cassava, an important crop of the tropical
uplands, was an obvious target for international research attention. From amongst the many small farmers crops CIAT chose to focus on cassava because of (a) its potential yield, (b) its status as a poor man's crop, and (c) the fact that, in spite of its widespread cultivation in the poorer rural areas, it was almost completely neglected by the agricultural research and development community.

Cassava originated in the American tropics where most of its diversification took place. It was widely distributed throughout the lowland tropics of South and Central America before the arrival of the Europeans in the 15th century, but did not exist outside the American continents (Cock 1985a). In the post-Colombian era, the crop spread rapidly, first to Africa and later to Asia, where the importance of the crop nowadays far outweighs that in the original American continents. As in many other crops, productivity tends to be greater in regions located farthest from its centre of origin and diversification (Jennings and Cock, 1977, Hernandez Bermejo and Leon, 1994).

Germplasm variation of a crop species is richest in the center of origin and diversification of the species (Vavilov, 1926; Harlan, 1975). When scientists began to examine cassava germplasm from around the world in the period from 1960-1990, they observed that almost all the variation in cassava germplasm existed in the American tropics. The African and Asian germplasm consisted of a part of the American germplasm and its local recombinants (Rogers and Appan, 1970; Kawano et al, 1978a; Hershey, 1987; Bonierbale et al, 1995). Furthermore, while the vast majority of diseases and pests that attack cassava were present in America, Asia was relatively free of major biotic constraints and Africa occupied an intermediate position (Bellotti and Schoonhoven 1977, Lozano et al 1981). Hence almost all the genetic variability, the pests and diseases, as well as natural enemies of the crop pests, would be expected to be concentrated in the regions surrounding the center of origin and diversification of the crop.

This background made Colombia, South America, a logical location for an international center for cassava research, with its purpose to focus inter alia to produce improved germplasm for use throughout the world. The importance of wide germplasm variability for the success of an international breeding program was well recognized and CIAT made an early strategic decision to conduct a comprehensive collection of cassava germplasm in South and Central America.

We were charged with setting up the breeding program in the euphoric period just after the Green Revolution in which standard cultivars such as IR8 rice and the Mex Pak wheat swept the world. If they did not fit into an environment, then the environment was modified with inputs such as fertilizer and irrigation to make growing conditions homogeneous. The technology required high inputs and intensive management such as the use of high plant density and thorough weed control. Nevertheless it was evident that we could not expect the poor small-scale cassava producers, who were our target population, to solve their problems by modifying the environment with expensive amendments and inputs such as irrigation. The resolution of production problems by genetic improvement of the crop rather than altering the environment was the basic premise behind the inauguration of the cassava program. Very early on, we made the critical decision to go for the adaptation of cultivars to the local conditions, low inputs and technology that did not require
intense management. This led to breeding for low input conditions in less favorable environments where cassava seemed to be more productive than most other crops (Cock 1982) rather than breeding for high yield with high inputs in favorable environments. With the progress of breeding activities and recognition of the production potential of improved cassava cultivars under marginal conditions, our objectives gradually shifted from one of sole productivity to alleviating the poverty of small farmers through income generation on marginal lands. As we gained more insight into the constitutional mechanisms and the exploitable genetic variation available to be exploited, stability of yield performance, within broadly defined agroecological zones, over years (temporal stability), locations (spatial stability) and cultural conditions (system stability) was added as an important breeding objective (Cock, 1985b).

From its initiation, the CIAT cassava breeding program was seen as a partnership between an international center and the national breeding programs carrying out a seamless continuum of activities. CIAT itself did not release cassava cultivars but was involved in all the phases of varietal improvement in a collaborative effort in which the national programs released the new cultivars.

II-2. Institutional and research support. As germplasm was collected and breeding work proceeded, a large number of ancillary research and support activities were established. Pathologists and entomologists, for example, provided vital information on the presence or absence of biotic constraints in the different cassava growing regions. From the inception of the cassava program it was clear that success could only be achieved by working closely with competent breeders and researchers in related disciplines in strong national programs. CIAT organized training programs and workshops for Asian breeders and researchers from national research institutions long before CIAT moved to Asia. Thus the institutional framework of competent Asian national programs was established. This setup, backed by the ancillary research described above, was in a position to exploit the strengths of the advanced breeding materials we were able to offer to the Asian national programs. The prerequisites for creating a highly functional joint breeding program in Thailand and of inducing close collaboration with various national programs were in place.

A key decision was made to transfer the major applied breeding effort to Asia, whilst maintaining a strong genetic improvement scheme in the center of origin, on the understanding that a crop is usually more successful outside the center of its origin and diversification than at the center of origin (Jennings and Cock, 1977). An applied breeding center was established as a joint operation with the Department of Agriculture in Thailand, which was originally selected for technical reasons such as excellent support, free germplasm exchange, and many other favorable natural and institutional conditions as the best venue for a collabative breeding program. It is worth noting in the present age of short-term projects that this successful program was developed over three decades. The administrators and donors gave the researchers the tools and the scientists responded to this with well focused but long term production-oriented research. There was no question of doing research for research’s sake: all efforts were geared to winning the war on
poverty in the marginal areas.

II-3. Collection of genetic materials. The collection covered all the countries that were believed to be the center of origin and diversification (Table 2). Collection proceeded without any impediment from national agencies on the tacit understanding that CIAT, a newly established non-profit international research organization would collect, evaluate, and maintain the genetic resources for the improvement of world cassava, and that the initial collections and the advanced materials derived from them would be freely available to any public organization.

Distribution of breeding materials to national programs in America, Asia, and Africa started in 1975 mainly in the form of F1 hybrid seeds. Asian national programs received the largest share. In the 23 years from 1975 to 1998, 485,717 seeds from some 3,500 cross combinations were distributed to 9 countries in Asia (Table 3).

The government of Thailand authorized free transfer of any breeding materials generated by

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<tr>
<td>Argentina</td>
<td>16</td>
</tr>
<tr>
<td>Bolivia</td>
<td>3</td>
</tr>
<tr>
<td>Cuba</td>
<td>74</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>5</td>
</tr>
<tr>
<td>Guatemala</td>
<td>91</td>
</tr>
<tr>
<td>Paraguay</td>
<td>192</td>
</tr>
<tr>
<td>USA</td>
<td>9</td>
</tr>
<tr>
<td>China</td>
<td>2</td>
</tr>
<tr>
<td>Fiji Islands</td>
<td>6</td>
</tr>
<tr>
<td>Indonesia</td>
<td>51</td>
</tr>
<tr>
<td>Malaysia</td>
<td>67</td>
</tr>
<tr>
<td>Philippines</td>
<td>6</td>
</tr>
<tr>
<td>Thailand</td>
<td>31</td>
</tr>
<tr>
<td>Nigeria</td>
<td>19</td>
</tr>
<tr>
<td>CIAT-hybrid</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2,218</td>
</tr>
</tbody>
</table>
Table 3. Cassava breeding materials distributed from CIAT/Colombia and CIAT/Thai to Asian national programs

<table>
<thead>
<tr>
<th>Country</th>
<th>No. of F1 seeds from CIAT/Colombia during 1975-1998</th>
<th>No. of F1 seeds from CIAT/Thai during 1985-1998</th>
<th>No. of selected clones from CIAT/Thai during 1987-1993</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thailand</td>
<td>177,331</td>
<td>28,650</td>
<td>17</td>
</tr>
<tr>
<td>Indonesia</td>
<td>78,224</td>
<td>21,030</td>
<td>23</td>
</tr>
<tr>
<td>China</td>
<td>76,246</td>
<td>25,320</td>
<td>48</td>
</tr>
<tr>
<td>Vietnam</td>
<td>51,206</td>
<td>11,894</td>
<td>26</td>
</tr>
<tr>
<td>Philippines</td>
<td>61,681</td>
<td>3,641</td>
<td>26</td>
</tr>
<tr>
<td>Malaysia</td>
<td>18,587</td>
<td>5,500</td>
<td>23</td>
</tr>
<tr>
<td>India</td>
<td>19,242</td>
<td>750</td>
<td>26</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>1,500</td>
<td>1,700</td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myanmar</td>
<td>950</td>
<td></td>
<td>13</td>
</tr>
<tr>
<td>Israel</td>
<td></td>
<td>750</td>
<td>13</td>
</tr>
<tr>
<td>Laos</td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>Nepal</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>CIAT/Colombia</td>
<td></td>
<td>14,068</td>
<td>52</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>485,717</strong></td>
<td><strong>112,553</strong></td>
<td><strong>286</strong></td>
</tr>
</tbody>
</table>

The CIAT/Thai program, including those using Thai germplasm, to other countries in the region, fully understanding that the Thai cassava industry would be the primary beneficiary of the CIAT/Thai breeding activity. The venerable Thai traditional cultivar Rayong 1 had supported the development of Thai cassava industry for nearly three decades and its greatness is further testified by the fact that several broadly adapted high yielding cultivars were selected from crosses of Rayong 1 with CIAT/Colombia genotypes.

A total of 112,553 F1 seeds and 286 clones were transferred from CIAT/Thai to 13 Asian countries and CIAT/Colombia in 13 years starting from 1985 (Table 3). They are now making outstanding contributions to cassava production in Thailand and other Asian countries, and are highly appreciated as breeding materials worldwide.

CIAT kept its word of honor by later returning the best available advanced breeding materials to the countries of origin upon request with no strings attached.

II-4. Breeding progress. A comprehensive cassava breeding endeavor, initiated by CIAT (headquarters in Colombia and its regional program in Thailand) in 1973 and later involving a network of national breeding programs, is now witnessing the economic effects generated by the adoption of new cultivars (CIAT 1974, Kawano 1995, 1998, 2001).

There have been three phases of successful varietal improvement. The first phase corresponds to the evaluation of cassava germplasm and the generation of advanced breeding materials conducted at the CIAT headquarters from 1973 to 1982. We attained, in this phase, a significant upgrading (90%) of physiological yield potential (measured by fresh root yield) of the breeding...
population (the average yielding capacity of selected clonal population to be used as cross parents for recycling the hybridization program) compared to the starting population which consisted of mostly traditional land races (Fig. 1). In this process, enhanced (55%) harvest index (proportion of root weight in the total biomass) was the major factor for improvement (Fig. 2, CIAT 1975, 1982, Kawano et al 1978a,b).

The second phase corresponds to the Thai-CIAT collaborative cassava improvement program conducted at the Department of Agriculture and Kasetsart University from 1983 onward. In this phase, we accomplished, using the local materials and the advanced materials from CIAT/HQ, a significant upgrading (50%) of dry root yield of the breeding population (Fig. 3). In this process, enhanced biomass (25%) and root dry matter content (15%) were the major factors for the progress (CIAT 1992, 1994, Kawano 1998, 2001, Kawano et al 1987, 1998).

II-5. Varietal dissemination. The third phase corresponds to the selection of new cultivars,

![Diagram showing relationship between biomass and harvest index at 10 months after planting of the 1,950 germplasm accessions evaluated in Single-row trial at CIAT/HQ (The values of the control cultivars are indicated with the standard deviation; See for the description of trial Kawano et al. 1978a).](image)

Fig. 1. Relationship between biomass and harvest index at 10 months after planting of the 1,950 germplasm accessions evaluated in Single-row trial at CIAT/HQ (The values of the control cultivars are indicated with the standard deviation; See for the description of trial Kawano et al. 1978a).
their release and dissemination by national programs. While Thailand naturally attains the largest acreage planted with new cultivars, Vietnam shows success in this varietal development more dramatically than any other country. Training of national program researchers at CIAT/Colombia and the offer of advanced breeding materials strengthened cassava breeding programs in Thailand, the Philippines, Indonesia and China, leading on to the establishment of cassava breeding programs in Malaysia and Vietnam. Their selection schemes were modeled after that of CIAT/Thai replete with F1 plant selection, Single-row trial, Preliminary trial, Advanced trial and Regional trials (see for the description of trials; Kawano et al 1998). Selected clones, large number of F1 hybrid seeds from CIAT/Thai and CIAT/Colombia, and a small number of F1 hybrid seeds produced at each national program passed through this selection scheme routinely during the 1980s and 1990s. The multiplication of planting stakes of the released cultivars and their dissemination differed between countries. In Thailand, the national agricultural extension agencies managed a well structured scheme (Limsila et al 1998, Sarakarn et al 2001). In Indonesia, the strong initiative of a
Fig. 3. Yearly progress in yield level and change in yield components of the breeding population at CIAT/Thai from 1982 to 1997 (Mean of all the clonal entries in yield trial (Regional trials) relative to the control mean is shown each year; Regression equation was determined by designating year 1 to 1982; See for the description of trials Kawano et al. 1998b).


By 1999, Asian national programs had released 38 CIAT-related cassava cultivars in six countries and farmers grew these new cultivars on one million ha (see for the references in Table 4).

II-6. Economic benefits. Hundreds of farmer-managed varietal trials were harvested between 1994 and 1996 in Thailand, Indonesia, and Vietnam. In general with the newest cultivars, farmers obtained 1 to 10 t/ha additional fresh root and the factories reported an additional 1 to 6 percentage points more root starch (Kawano,1998; Puspitorini et al, 1998; Kim et al, 1998).
Table 4. Asian institutions where cassava cultivars selected from CIAT-originated materials were released

<table>
<thead>
<tr>
<th>Country</th>
<th>Institution</th>
<th>Category</th>
<th>No. of cultivars</th>
<th>Estimated acreage by released cultivars in 1999 (1000ha)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kasetsart University</td>
<td>National</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>Umas Jaya Corporation</td>
<td>Private</td>
<td>4</td>
<td>130</td>
<td>Puspitorina et al, 1998</td>
</tr>
<tr>
<td></td>
<td>Vietnam Agricultural Science Institute</td>
<td>National</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thai Nguyen University</td>
<td>Provincial</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>Leyte State University of the Philippines</td>
<td>Provincial</td>
<td>8</td>
<td>6</td>
<td>Mariscal et al, 2001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>National</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Chinese Academy of Tropical Agricultural Sciences</td>
<td>National</td>
<td>1</td>
<td>3 (combined)</td>
<td>Lin et al, 2001</td>
</tr>
<tr>
<td></td>
<td>Guanxi Subtropical Crops Research Institute</td>
<td>Provincial</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>Malaysian Agricultural Research and Development Institute</td>
<td>National</td>
<td>2</td>
<td>0.2</td>
<td>Tan, 2001</td>
</tr>
</tbody>
</table>

Total 38 998.2

The aggregate figures for SE Asia provide a total estimated economic effect attributable to the superior yield and quality of new cultivars accumulated up to 1997 to be greater than 600 million US dollars (Puspitorina et al. 1998, Rojanaridpiched et al. 1998, Kawano 1998, 2001). As the area planted with improved cultivars increased to one million ha in Asia, there were marked drops (some 25 - 42%) of cassava product price in South Vietnam in 1997 and in Thailand in 1999 due to regional overproduction. The association of price drop with the adoption of yield enhancing technology appears to be the destiny of all farmers producing cash crops with consumers eventually receiving a large proportion of the benefits of cost reducing technology. The present analyses on economic effects are based on the value of cassava starch produced without taking into account the production and processing costs. As most of the new cultivars grown throughout Asia have higher starch content, the harvesting and processing costs per produced unit starch will have been reduced, contributing to substantial economic benefits beyond those already estimated above.

Furthermore, the present analyses do not include secondary or indirect effects such as sales of planting stakes or additional employment. Nevertheless, even taking into account price fluctuations
related to increased production and the somewhat complicated value scheme for fresh roots and starch, yet doing so without considering the potentially large effects of increased starch content per se on harvesting and processing costs for starch, the accumulated economic benefits estimated by a conservative extrapolation surpassed one billion US dollars in the year 2000.

II-7. Profits to small farmers. The farmers who have adopted the new technology have in general not been forced to increase neither the purchased inputs required nor the labor input to produce a hectare of cassava, and hence their production costs have not been increased. Harvest costs may have been increased proportionately with the increase in production of fresh roots; however, as noted above the harvesting costs per unit of starch will undoubtedly have been reduced when higher starch cultivars have been adopted.

Virtually all cassava in Thailand is produced in small farmers’ fields and the harvest is sold exclusively to processors. Similarly, in Vietnam, all the cassava is produced by small farmers. At present those advanced farmers in South Vietnam who adopted the new cultivars sell their harvests to the processors whilst in North Vietnam they use cassava mostly for feeding their pigs to be sold to the market. In Indonesia and the Philippines, some large plantations produce cassava; yet, most cassava is still produced by small farmers. Thus, we can assume that virtually all the additional economic effects generated by the higher fresh root yield of new cultivars are entering directly into the pockets of small farmers.

How much of the additional profit generated by the higher starch content of new cultivars is shared by the farmers depends on the price differential starch factories (or chipping plants) pay to the farmers. Large factories in Thailand, Indonesia and Vietnam return 55 to 100% of the value of the additional starch produced as a result of increased starch content of fresh roots to the farmers. Hence, we can safely assume that a substantial portion of the hundreds of million US dollars generated by the adoption of new cultivars has entered the household of those small farmers and helped boost their income.

The recent varietal dissemination in North Vietnam revealed that thousands of small farmers are adopting new cassava cultivars on small plots (360-5000 m²). Virtually all of them use the additional cassava yield for pig feeding which results in 50-600 kg additional pig sale worth US$45-545 per family per a year to the market (Ngoan et al, 1998). The whole scheme is not as spectacular as the rapid varietal dissemination in South Vietnam or other countries, but the extra income of US$45-US$545 is undoubtedly of great significance to those individual rural families that have adopted the new cultivars. Here is a scheme where a new technology is widespread and there is an equitable distribution of the benefits, creating new economic opportunities that improve the well being of a large number of farmers and their families.

III. Common Human Heritage

III-1. Utilization of genetic resources. Formation of a population creates a framework whose
potential is open-ended. Selection within that population operates within a framework where the potential is predetermined. The great initial germplasm variation seen in the 1973 CIAT/HQ trial (Fig. 1) set the basis for the overall progress during the following thirty years. Few large-scale international breeding programs start with this magnitude of genetic variation and in retrospect, we were very fortunate to have started the breeding program giving equal importance to all the germplasm materials instead of starting with a certain predetermined population. The 20th Century masterpiece “A Hundred Years of Solitude” by the great Colombian writer Gabriel Garcia Marquez begins with a sentence, “The world was so new, many things did not have even a name,” alluding to the fact that undefined happenings in the beginning may decide the long-lasting structure of the future.

The great diversity of evaluation and selection environments very likely rendered wide adaptability to the breeding materials while maintaining a large genetic variability in the population. Particularly, the selection input from the most stressful environment in the Colombian Eastern plain (Llanos) must have been crucial in securing tolerance to poor acid soils and disease resistances in the breeding populations, which were to be brought to Asia through seed transfer. The Cassava bacterial blight and Super elongation disease resistances obtained in the Llanos selections were quantitatively inherited, slow disease-growing type (Umemura and Kawano, 1983; Kawano et al, 1983) and these resistances appear durable both in America and Asia up until now. The breeding populations thus generated and further improved at CIAT/Thai were undoubtedly the source of successful cultivar selections for cassava-growing environments in Asia. Besides, as Asia is far from the center of origin and diversification of cassava, the number of biotic constraints is much less in Asia than in the Americas. Diseases such as Superelongation disease (Elstonoe brasiiliensis), Concentric ring spot (Phoma spp.) and Dry root and stem rot (Diplodia manihotis), as well as pests such as Cassava hornworm (Erinnyis ello), Mealy bugs (Phenacoccus spp.) and Lace bugs (Vatiga manihotis and V. illudens) all cause serious damage to cassava in Latin America but they are not known in Asia (Lozano et al, 1981). The end use of the product in Asia is largely limited to raw materials for starch and animal feed production; thus, the quality requirement is less complicated in Asian cassava. Here again, technology developed in the center of crop origin and diversification had better chances of success outside the center of origin (Jennings and Cock, 1977).

While broad genetic variability characterized the CIAT/Colombia and CIAT/Thai breeding populations, one particular genotype made an outstanding contribution as a source of desirable characters. MCol 1684 was collected in a village near the Colombian Amazon town of Leticia in 1971. MCol 1684 not only showed one of the highest harvest indices among all the accessions but also proved to be the best cross parent for producing high harvest index progeny. MCol 1684 was the most frequently used clone in the early years of the CIAT hybridization scheme. In Asia today, 14 cultivars grown extensively in 6 countries are selections from MCol 1684 derived populations. There is no doubt that MCol 1684 was nurtured and selected, after its chance appearance as a seedling, by the Amazonian Indians. Its excellent genetic ability supports cassava yield
improvement in many parts of the world. What would be the reaction of the Amazonian Indian village people who amicably donated MCol 1684 to the CIAT collecting expedition if they were to know that their cultivar makes a major contribution to the livelihood of small farmers in Northeast Thailand, North Vietnam, or Mindanao, in the Philippines?

III-2. Intellectual property right?. Indigenous crop cultivars, which have been brought to this world through thousands of years of conscious and unconscious breeding efforts by our ancestors, are the major constituents of the existing crop genetic resources. There is no doubt that they are the assets belonging to the farmers. Given that nearly all the crop species had been domesticated and differentiated in the tropics and sub-tropics, it is legitimate to consider that the genome of all the indigenous crop cultivars are primarily a cultural heritage of the farmers in the South.

Intellectual property right, in its primary implication, was a priority arrangement to be granted only to an intellectually created original entity. However, the recent reports from USA suggest that the US patent office is ready to accommodate applications for gene patenting once the structure of the gene is detected even without establishing its function. If a patent applicant tries to make profit by patenting a gene(s) which is a borrowed resource not originally produced by him, it would naturally invite a protest from the primordial owner. More importantly, even a highly functional gene is nothing more than a sequence of bases if it is not backed up by the whole genome that has been nurtured by the farmers for the past thousands of years. Naturally in this context also, it is absurd to insist for an intellectual property right on a part of genome that is fundamentally a common human cultural heritage.

Needless to say, good cultivars are rarely made by adding a new technical innovation or two. They are usually brought about as an integration of many factors through many technical steps. Hence, intensification of patent competition for technical process would lead to a situation where many patents belonging to different enterprises crisscross in the breeding process and the breeders would have to spend more time and energy in court negotiation rather than actual breeding. Furthermore, patenting on technical process would hinder the utilization of patented technology by public institutions in breeding of less lucrative crops such as barley or cassava, which patent owning corporations would not wish to deal with due to the low expected economic return. This situation, after all, would not lead to a long-term benefit of any party. The claiming of intellectual property right by big corporations in the North is already pressing many countries in the South not to recognize intellectual property right on genetic resources.

I herein repeat, we the breeders at IRRI, CIMMYT, and CIAT during the 1960s and 1970s never doubted that plant genetic resources were a common human heritage. It was our duty to use these resources for the welfare of all human beings. This may sounds too naive in these days of instant gratification and short term projects. Yet, precisely on this account, I consider it meaningful to recollect the great breeding works that have been accomplished with such naive idealism and motivation.
Summary

The purpose of this paper is to present a case for fair and effective genetic resource utilization as well as a concern about the abuse of intellectual property right on plant genetic resources. The CIAT Cassava Breeding Program was conceived in the beginning of the 1970s with the understanding that plant genetic resources were part of mankind’s heritage and it was the duty of agricultural scientists to effectively utilize these resources for the welfare of all human beings. The initial decade of this program was mainly dedicated to the collection of germplasm and generation of basic breeding materials. The later decades were devoted to applied breeding in collaboration with national programs in Asia and Latin America. By 1999, Asian national programs had released 38 CIAT-related cassava cultivars in six countries and farmers grew these new cultivars on one million ha. The economic benefits resulting from the increased productivity is in the order of one billion US dollars. The target population of small farmers in the poorer rural areas of the tropics captured a large proportion of these economic benefits. The most critical biological factors for this successful breeding effort was the inclusion of a broad base genetic variability obtained in the center of crop origin and diversification in Latin America. The collection of genetic materials proceeded without any impediment from national agencies on the tacit understanding that CIAT, a newly established non-profit international research organization, would collect, evaluate, and maintain the genetic resources for the improvement of world cassava, and that the initial collections and the advanced materials derived from them would be freely available to any public organization. CIAT kept its word of honor by later returning the best available advanced breeding materials to the countries of origin upon request. However, at present, large private corporations are patenting on genomic materials and technical processes. Such activities would hinder the utilization of patented technology by public institutions in breeding of socially important crops. It is time we should reflect back on those days when great breeding works were accomplished with fairness and idealism.

Acknowledgement

The concept presented in this paper is thoroughly based on the accomplishments by the CIAT Cassava Breeding Program. I thank the hundreds of persons who worked together or helped during the course of program activity. Special appreciation is due to James H. Cock, founding Director of CIAT Cassava Program, who set the overall framework of international cassava research, Pablo Daza, erstwhile Head Technician, CIAT/HQ, who supported the efficient field operations in the early years, Clair Hershey, former CIAT Cassava Breeder, for providing much of the sexual seeds for the Asian Programs, Charn Thiraporn, former Director, Rayong Field Crop Research Center, Thailand, who provided the best imaginable working condition for breeders, and Hoang Kim, Director, Hung Loc Agriculture Research Center, Vietnam, who organized the most efficient
varietal development and dissemination scheme in the national program. I also thank James H. Cock for providing much idea in this writing and Kaede Hirohashi for checking the English of manuscript.

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人類共有資源としての作物遺伝資源とその利用

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遺伝子やゲノムに対する特許が語られる昨今であるが、この論文の目的は、著者自身が全面的に進めてきたキャッサバ育種に基づいて、有効かつ公正な結果を出した遺伝資源利用の例を示し、一方で遺伝資源に関する行過ぎた知的所有権主張に対する懸念を述べる事にある。CIAT（本部コロンビア）キャッサバ育種プログラムは、1970年代初頭、植物遺伝資源は人類共有資産であり、この資産を全ての人々の為に有効に利用するのが農業科学者の務めであるとの理解のもと設立された。最初の10年間は主として遺伝資源の収集と基礎育種材料の育成に力を注ぎ、それに続く20年間はアジア、ラテンアメリカ各国の研究機関と共同で改良品種の育成と普及に努めた。この仕事の結果として1999年度末にはアジア6カ国で38品種が登録され、その栽培面積は100万haに及んだ。新品種作付けによる付加経済効果は10億ドル以上に達したと推定されるが、最も重要な事はその付加経済効果の大きな部分が畑畑小農家の現金収入に直結した事である。育種を始めるにあたり、キャッサバの進化・分化の中心地から得られた膨大な遺伝変異を全て含めて仕事を進めた事が、この仕事を成功に導いた最も重要な生物学的要因の一つである。遺伝資源の収集は、新たに設立された非営利国際研究機関である CIAT が、世界のキャッサバ改良のため遺伝資源を収集・検定・保存し、集められた材料やそれを使って作成された改良育種材料は、求めに応じて全ての公共研究機関に提供されるという理解のもと、何の支障も少なく進んだ。CIAT はその後現在に至るまで育種材料を原産地国は言うに及ばず世界各国に無条件で提供し続け、最初からの約束を守っている。自分が作ったわけではないゲノムにパテントを設定したり、結果を最も必要としている社会的弱者の為に技術が使われる事を妨げる事にもなる知的所有権の主張が叫ばれる21世紀に、遺伝資源は社会的弱者にも平等にといった理念は素朴な理想論だと言われそうである。こういう時代だからこそ、その素朴な理念のもと成し遂げられた多くの偉大な仕事に思いをはせるのは意義深いと考える。
質疑応答

質問者：ひとつの形質遺伝子の変異だけで非常に重要な進歩がある場合もあるでしょうから、それに対しては非常に重要な業績と認めてそれに対する権利を認める必要があるというのです。

河野：非常に難しいところで先ほど申し上げたが、オリジナルな実体ということが当然キーワードになるわけです。私は法律家ではありませんから単なる育種家としての感想を言えだけですが、まったく新しいものを見つけてきてそれが役に立つことが証明されたものについては、当然の認定はすべきでしょう。ただちょっと気になるのは、今ある技術ですと、遺伝子というのは、元々自然にあったものから見つけてこないと、ますます役に立たないわけですから、パテント等として認められるかどうかは微妙だと思うます。一方で例えば、「ＢＴジーン」などはオリジナルな実体に近いと思いますので、パテントをとっても全く問題ないと思います。

丸山：知的所有権、もっと言えば工業所有権の事に関しては、私も先生のおっしゃる事について、とても納得いたします。発明と発見の違いということですね。ゲノムという、もともと自然の進化の中で機能の変容があったものに特許を設定するというのは少し変だという議論は納得できます。技術的なことを質問させていただきます。図中（注：要旨 Fig.1）には200ものキャサバの遺伝資源がありますが、中にはバイオマスで1植物あたり20kgもあって、ハーベストインデックスが6.0くらいあるような品種もあります。こういったものが母本になれば、ハーベストインデックスのもっと高いものが良い母本になったということですが、多収でハーベストインデックスがやや高い品種を、実際に交配の対象になさったのかどうか、勘で観察しては全然ダメそうだからやめたのか、交配したが良いものが出てこなかったのか、お聞かせします。

河野：これはジャームブラズコレクションの最初の検定結果で、1列1系統の試験です。ということは、本当に品種として植えた場合にこれが再現されるかというちょっと別問題です。でも、育種側としては当然この辺のもの（注：要旨 Fig.1、中央左上のもの）を交配ブロックに組り込みます。1列1系統でやっているこの辺のものは極めて収量が高いです。しかし、この収量の高さは仮の姿であり、競争に勝っているだけです。この辺のもの（注：要旨 Fig.1、右下部のもの）はまず見当らないです。ただ、あまりにも大きいものは一致交配をしますが、別なものは出ないです。キャサバはサイクル長いですから、その辺の呼吸がわかるのに3、4年かかっています。最初にこの辺のもの（注：要旨 Fig.1、中央左側上部のもの）を優先させたということはたぶん、大正解だったと思います。

岡崎：発展途上国で育種をやった場合、オーソドックスな育種法というのが、すごい成果を上げるというのはあります。先生のお話のように、ただ、日本みたいに発展した国ですと育種目標は非常に細かくなっていてややこしい育種の状況になっています。キャサバは、いまうまくいっていますけどたとえば生産過剰になった場合に、国益とかなんとかいうことになって共通の財産とかいう利点に染まっていくとか、そういう懸念もあるのではないかと思いますが、そういったややこしい状況にどういうふうに対応して
いったらいいのでしょうか。
河野：まず後段の方にお答えします。キャッサバは、現金作物です。ですから生産過剰による価格の下落というのは宿命です。家畜の飼にするかそれとも輸出用にするか自国用の食品にするか、それともデンプンにするか、そのデンプンも食料としてのデンプンにするか、それとも味の素だから市場価値の高いアミノ酸のリンを作るためのものにするかといったその国にとっての選択肢はあるわけです。非常に早い段階から、必ず、こういった「わけ口」というものを視野に入れていかなければならないと考えて育種を行ってきました。しかし、国の政策からマーケティングの状態までを育種家が変えられるかというと、それは非常に難しい。それでもそれを無縁で育種をしてはだめです。いくらいい品種を作っても「わけ口」がなければ意味がないということです。前段の質問についてですが、発展途上国で育種法が未発達な段階で育種をした時に非常にうまく行く場合があるのではいかがかと言いますと、それは、イエス＆ノーです。まだ在来品種の中に大変な多様性が残っていると、育種は非常にうまく行く可能性があります。と同時に、育種というのは数のゲームです。発展途上国では、「お金がない、設備もない、人もあまりいない。」ということで、育種で結果を出せる最低限のスケールを絞らずに場合がほとんどです。そこに、CIATのような国際機関が、「途上国の比較的小さなスケールの育種プログラムでもある程度まで国際研究機関が典上げした材料を使って最後の検定をしっかりとすればいい品種が出る」という考え方のもとに育種を行って、ある程度の成果を出したということがあります。非常にうまく行ったベトナムの例では、この要素が強かったです。このベトナムでタイのCIATである程度出来たものをから選ぶというものと、F1集団を使って一から選抜するという2つのタイプの品種選抜をやりましたが、結局うまく行ったのは前者の方でした。
RICE BREEDING IN THE TROPICAL ASIA
— ONE OF THE ASPECTS —

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Introduction

Rice breeding in the tropical Asia has been led by the International Rice Research Institute (IRRI), which was established in 1960 in the Philippines. Although the national rice breeding was carried out in some countries, such as Indonesia, before IRRI was established, the institute became the center of rice breeding in the Area. The history of rice improvement at IRRI was described by CHANDLER (1979), KHUSH et al. (2002), or in annual reports of IRRI.

IRRI developed IR8 from the cross between Peta, an Indonesian variety, and Dee-geo-woo-gen, a Taiwanese variety. IR8 was the leading actor in the “Green Revolution” of rice in the tropical Asia. It has lodging resistance due to the semi-dwarf gene, which was introduced from Dee-geo-woo-gen, and realized high yielding with high input of fertilizer. IR8 was frequently used as cross parents not only at IRRI but also in the national rice breeding programs, and became the most important ancestor of Asian rice varieties.

After IR8, IRRI has developed varieties with shorter maturation period and multiple resistances to diseases and insects. IR36 was one of the offspring of IR8 and became the world leading rice variety in the tropical Asia. Planted area of the variety reached to 11 million hectare in the widest planted year. This is the highest record of planted area of a single variety of one crop in the world. The variety has short maturation of 120 days and multiple resistances to blast, tungro, brown planthopper etc. The following leading variety IR64 was also developed by IRRI. IR64 was improved in rice quality and disease resistance, and planted in paddy fields of nine million hectare.

IRRI has changed the policy of the breeding after IR72 and IR74 were released in 1988. Main targets of the research became breeding methodologies and genetic resources of rice. Varieties were considered as side-products of the research activities. However, still now, many countries including the Philippines introduced many IRRI breeding lines every year as commercially recommended varieties for their rice farmers.

Disease and insect resistances have been important targets of rice breeding for the tropical
Asia, because resistance is effective but low-cost pest management. In the rice breeding at IRRI, multiple resistances to diseases and insects such as blast, bacterial leaf blight, grassy stunt, tungro, brown planthopper, green leafhopper, gall midge etc., have been introduced into the IRRI varieties. Although these resistant varieties have been successfully used for pest management in rice production in the tropical Asia, there were also some negative factors in the resistant varieties. The author used to work on breeding of tungro resistance at the Malaysia Agricultural Research and Development Institute (MARDI), and blast resistance at IRRI. In this paper, these negative factors are discussed.

**Tungro resistance**

Tungro disease is the most serious virus disease of rice in South and Southeast Asia. Tungro infected plants show stunting, reduction of tiller number, yellowing of leaf color, longer maturation because of delayed flowering, small and sterile panicle, lighter grain often with dark brown blotches and low yield (Ling 1972). In Malaysia, tungro disease is known as ‘Penyakit Merah’ (the term means ‘red disease’), and has caused serious damage in rice production during the epidemic period from 1981 to 1982. Tungro disease is caused by a complex of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) (Saito et al. 1981). Hibino et al. (1979) found that RTBV was transmitted concomitantly only when RTSV was acquired previously or simultaneously by the green leafhopper, Nephotettix virescens Distant (GLH). This indicates that GLH could not transmit RTBV from singly RTBV-infected plants. Therefore, the role of RTSV as a “helper” in the transmission of RTBV (Hibino et al. 1979), is considered to be important in the epidemiology of tungro. Fig. 1 shows various patterns of transmission of tungro viruses. This interesting transmission characteristic is important for tungro resistance in rice.

Before IRRI started the breeding program, Indonesia had their own rice breeding program and released many rice varieties including Peta, one of the parents of IR8. Peta, Latisail, a parent of Peta, and some other varieties were classified as resistant varieties at the beginning of tungro studies (Ling 1972). The author found that Peta and Latisail were infected with both RTBV and RTSV, but virus concentrations were low in the infected plants of both the varieties. This indicated that Peta and Latisail possessed tolerance to tungro viruses. Tolerance of Peta was not introduced into IR8, which is highly susceptible to tungro.

Tungro became serious since mid 1960s. Most of IRRI varieties, except IR8, IR22, IR24, and IR43 have tungro resistance of various levels. Some of these resistant IRRI varieties have succumbed to tungro after a few years of intensive cultivation in some countries due to differential selection of GLH biotype (Hibino et al. 1990). These varieties were resistant to GLH but not to the virus (Hibino et al. 1990).

Hibino et al. (1987) showed tungro incidence on resistant varieties in the Philippines. These included IR36, of which GLH resistance was derived from Pt818. In Indonesia, tungro resistance
of IR36 and IR42 broke down in the areas where the two varieties were the most planted (MANWAN et al. 1987). They introduced rotation of the varieties to reduce the incidence of GLH and tungro. IR42 was introduced as a tungro-resistant variety in 1983 during the epidemic in Malaysia. MARDI had been using IR42 and IR36, a sister variety of IR42, as donors for tungro resistance in the breeding program. A GLH biotype adapted to IR42 could be selected (KOBAYASHI et al. 1983), and the variety became susceptible to tungro when it was inoculated with the new biotype (NEMOTO et al. 1995).

DAHAL et al. (1990) demonstrated increased incidence of tungro in IR54, IR62, and IR64, which were belonging to another resistant group of IRRI varieties. These varieties were resistant even after the breakdown of IR36. GLH resistance in these varieties was derived from Gam Pai 30-12-15. These incidences of the breakdown of tungro resistance indicated that resistance to virus disease by vector resistance is not stable due to occurrence of new vector biotypes.

After the history of breakdown of tungro resistance, virus resistance to RTSV was found in some IR varieties, such as IR20, IR26, IR30, and IR40 (HIMINO et al. 1988). These varieties harbored resistance to RTSV itself besides the resistance to the vector GLH. The RTSV resistance was supposed to be derived from TKM6 (Fig.2). RTSV resistance is expected to suppress the transmission of RTBV, and therefore, the varieties are resistant without GLH resistance. However,
these varieties were not planted widely except IR26. IR26 was the first variety with brown planthopper (BPH) resistance, but it showed breakdown of BPH resistance and was replaced with IR36. If these RTSV-resistant IRRI varieties were dominant in rice production, they would have suppressed (or escaped from) tungro epidemic.

A new strain of RTSV, which was virulent to the RTSV resistance in TKM6 was discovered in the Philippines (Cabaatuan et al. 1995). This suggested that even virus resistance could be broken down by a new race (or biotype) of virus. It is concluded that sources of resistance should be diversified to make it stable.

### Blast resistance

Rice blast caused by Pyricularia grisea is a serious constraint to rice production in both tropical and temperate regions (Ou 1980). In the tropical Asia, the disease is serious especially in rice area with water stress, such as upland rice ecosystem, or low temperature area at high altitude. Even in the flat plain irrigated area in the tropical Asia, rice showed disease incidence if rice varieties do not possess minimum resistance. Therefore, blast resistance has been one of the important targets of rice breeding at IRRI and in the national agricultural research systems in Asian countries.
To develop so-called “durable resistance” (JOHNSON 1979) in rice breeding programs, factors of resistance, i. e., complete resistance (or ‘true resistance’) and partial resistance (or ‘field resistance’) should be analyzed and accumulated. Partial resistance in test materials can be evaluated only when their complete resistance genes are identified. It is compared within the same gene group of complete resistance genes.

However, we had limited information on blast resistances in indica rice varieties including IRRI-bred varieties, despite the fact that many resistance genes were identified in indica varieties and their japonica derivatives. None of blast resistance genes in IRRI varieties had been identified. Genetic constitutions are relatively complicated in indica than in japonica, and therefore, not many studies had been carried out. Then, the author started the studies on complete resistance to blast in IRRI varieties.

A new resistance gene Pi 20 was identified in IR24 (IMBE et al. 1997), and some other known resistance genes were also identified in IRRI varieties (IMBE et al. 2000). Among these resistance genes, Pi 20, Pi ta, Pi k* (any of Pi k alleles except for Pi k-s) genes are important in relation with blast pahotypes in the Philippines. Then, we developed the differential system to estimate the existence of the three resistance genes in the tested rice materials, by inoculating with the three blast isolates of different pahotypes, which are avirulent to only one of the three resistance genes (IMBE et al. 2000).

Then, we compared the blast scores of IRRI varieties at the IRRI Blast Nursery (IRBN). Table 1 showed the blast scores of the IRRI varieties belonging to the groups based on the existence of Pi 20 and Pi ta, i. e., IR30 group (None), IR24 group (Pi 20), IR36 (Pi ta), and IR64 (Pi 20, Pi ta). Pi k* gene was not harbored in these variety groups.

<table>
<thead>
<tr>
<th>Varietal group (Resistance gene)</th>
<th>Variety</th>
<th>Disease lesion area b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1993</td>
</tr>
<tr>
<td>IR30 (+)</td>
<td>IR30</td>
<td>61.7</td>
</tr>
<tr>
<td></td>
<td>IR20</td>
<td>22.3</td>
</tr>
<tr>
<td></td>
<td>IR28</td>
<td>15.0</td>
</tr>
<tr>
<td>IR24 (Pi20)</td>
<td>IR22</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td>IR24</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>IR26</td>
<td>0.0</td>
</tr>
<tr>
<td>IR36 (Pi ta)</td>
<td>IR50</td>
<td>78.3</td>
</tr>
<tr>
<td></td>
<td>IR72</td>
<td>35.0</td>
</tr>
<tr>
<td></td>
<td>IR36</td>
<td>13.0</td>
</tr>
<tr>
<td>IR64 (Pi20, Pi ta)</td>
<td>IR46</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>IR48</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>IR64</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Blast scores were consistent with the known partial resistance of IRRI varieties. IR30, IR22, IR24 and IR50 have been classified as the low partial resistance previously, and showed higher blast scores in each groups. IR36 and IR64 have been known to possess partial resistance to blast, and showed lower scores. Varieties of IR30 group and IR36 groups showed higher blast scores than those of IR24 and IR64 groups. This indicated that blast pathotypes that are virulent to Pi 1a gene was dominant to those that are virulent to Pi 20 gene in the blast population at IRBN.

These results showed that classification by complete resistance genes was inevitable to evaluate partial resistance to blast. For example, IR22 or IR24 would be classified into the high partial resistance group like IR36, unless complete resistance genes of the varieties were known.

Conclusion

IRRI and the national agricultural research systems (NARS) have developed the rice varieties, which possessed multiple resistances to many diseases and insects. Not only to tungro and blast, they introduced resistances to brown planthopper, grassy stunt, bacterial leaf blight etc. These varieties have been useful and effective to control the diseases and insects.

However, in the resistance breeding, there were some problems mentioned in this paper. Mechanism or characteristics of the resistance (differences between virus resistance and vector resistance in tungro resistance, differences between complete resistance and partial resistance in blast resistance) were not well recognized.

In tungro resistance breeding, over dependence on the vector resistance lead the repeated breakdowns of tungro resistance. Some RTSV-resistant varieties existed before tungro epidemic, but could not be used to control the disease unfortunately. Infection of RTSV could not be determined by the symptom, and therefore, RTSV resistance could not be recognized. The enzyme linked immunosorbent assay (ELISA) enabled the screening of virus resistance. We had to wait the pathological studies on tungro (HIBINO et al. 1979) and virus purification (OMURA et al. 1983).

In blast resistance breeding, the concept of complete resistance (true resistance) and partial resistance (field resistance) must be introduced. However, genetics of blast resistance in indica rice are so complicated that breeding lines have been evaluated their blast resistance simply by the scores at blast nurseries without any information of complete resistance. Now, at least, we have developed the differential system for important blast resistance genes in IRRI varieties. In future, other resistance genes will be accumulated in the IRRI varieties and genetic constitution will be more complicated, and therefore, new methodologies to identify blast resistance genes should be introduced. DNA markers will be one of the most powerful methods.

In the NARS breeding programs, these concepts or methodologies will not be introduced easily, and therefore, the same mistakes will occur possibly. One of assistances to the NARS breeding should be focused to methodologies for selection of resistance. Collaborations with pathologists or entomologists are also important to understand mechanism and characteristics.
Reference

熱帯アジアのイネ育種 —その一側面—

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1960年にフィリピンに設立された国際稲研究所以（IRRI）は、インドネシア品種のPetaと台湾品種の低脚鳥尖組合せからIR8を育成し、いわゆる「緑の革命」に貢献した。また、耐病性などが改良されたIR36やIR64は、世界中で広く栽培された。現在でも毎年数千万のIR系統が、地元のフィリピンを始めとする熱帯アジアの各国で品種として採用されている。収量性は徐々に改良されたものの、頭打ちを打開するために、ハイブリッド品種の育成と少けつ穂重ねの新型品種（New Plant Type）の育成が行われている。

ツングロ病、タイワンツマグロコバイ（GLH）が媒介するRTBVとRTSVの2種類のウイルスによって起こる熱帯での重要病害であり、二期作の普及により発生が拡大したと考えられる。主要のIR36とIR42の抵抗性が崩壊するという現象が各地で発生し、さらにIR50やIR54などの代替品種が、再び抵抗性を喪失した。その結果、これらのGLH抵抗性によるツングロ病抵抗性が見直され、ウイルスへの抵抗性育種が開始された。ウイルスが純化され血清診断手法（ELISAなど）を利用してできるようになり、ウイルス抵抗性研究が進展した。また、育成品種の中でもTKM6に由来するIR20, IR26, IR30などの初期のIRRI品種などにRTSV感染抵抗性が見出された。IR36ではなく、これらの品種が主力になっていれば、ツングロ病は大きな問題とはならなかったかもしれない。当時は診断手法がなかったため、このようなウイルス抵抗性を活用することができなかったのが残念である。

いもち病抵抗性では、IRRIの育種では、稲状態での検定圃場で発病の少ないものが「抵抗性」として選抜され、高抗性と圃場抵抗性を区別することはなかった。そこで、IRRI品種の遺伝子分析を行い、新しいPi20を含めて多くの遺伝子を見出した。これらの遺伝子のうち、Pita、Pi20、Pikの3遺伝子はレースの動向に関わる遺伝子であると考え、この3遺伝子に対して異なる非病原性を持つ3つの菌系を用いて、品種・系統内の3遺伝子の有無を推定するシステムを考案した。こうして、真性抵抗性で類似した品種を群内で比較すると、圃場抵抗性の差がはっきりすることを示した。いもち病抵抗性のこのような評価手法は日本国内では当たり前のことであるが、熱帯アジアではなかなか取り入れられそうにない。真性抵抗性遺伝子を推定する方法を確立することの方が先決である。

IRRIの品種は多種類の病害虫に対して抵抗性遺伝子を蓄積してきており、IRRIの育種の成果は極めて大きい。しかしながら、病害虫にとっては抵抗性のメカニズムや特徴を十分把握されずに育種が進められてきた側面があり、抵抗性の崩壊などが生じる結果となっ
た。日本からの研究協力では、もち病抵抗性を真性抵抗性と圃場抵抗性の両面から評価して選抜するようなきめ細かさという側面を重視することも重要であると考えられる。

質疑応答
河野：horizontal resistance と vertical resistance の世界というのは理論的には極めて exciting で，いかにもいいものができるなと納得がありました。また，phylogeny 的に非常に異なる菌に対する真性抵抗性を与えればそれを侵す菌が出る可能性が非常に少ないというような理論もありました。それぞれ大変魅力的な理論ですが，その理論を元に良い抵抗性品種ができたという話を聞きません。このことについてどのようにお考えでしょうか。

井辺：IR64 や IR36 は horizontal resistance というか partial resistance（圃場抵抗性）の非常に良い遺伝子を持っていますが，それは圃場抵抗性を選ぶということで選抜されたのでなくて，たまたま選ばれてきたものです。IRRI では単に強いものということで選抜しているために，IR50 という，IR36 と同様に Pita 遺伝子を持っている品種を開発しかったが，こちらはもち病が激発したということがあります。最初から圃場抵抗性で選抜する等の戦略を考えて良かったのではないかと思います。また，アメリカや CIAT では lineage という概念がありますが，それはレースの問題と混同しています。しかし，Durable な resistance を選ぼうということは一致した方向であり，真性抵抗性も圃場抵抗性も積極的に蓄積して行くのが良いというのが現在の方向性のようにです。
CURRENT STATUS OF WHEAT BREEDING IN THE DEVELOPING REGIONS

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Introduction

Wheat is one among the major cereal crops such as rice, maize, barley etc., which is produced and utilized in not only the developed regions but also in the developing regions. The developing regions under unfavorable environmental conditions produce less than half of the world quantity, but are supplied with more than half. The International Maize and Wheat Improvement Center (CIMMYT, headquartered in Mexico), founded in 1966 with the base of collaborative research program of the Mexican Government and the Rockefeller Foundation, has been implementing research and training on wheat production for the developing regions. Wheat varieties developed from the CIMMYT breeding program had a significant contribution in increasing wheat production in the developing countries with low latitude, such as Mexico, India, Egypt etc., and resulted in the Green Revolution in the 1970’s. However, there is a more urgent demand to ensure the stable and sustainable wheat production for meeting the rapid increase of population in the developing regions (Bonjean and Angus 2001). In this paper, current status of wheat breeding for increasing and stabilizing wheat production in the developing regions is summarized.

Production and supply of wheat in the world

According to the FAOSTAT (average of five years, 1995 - 1999) as shown in Table 1, main wheat production areas are the European Union, North America (USA and Canada), the former USSR (mainly Russia, Ukraine, Kazakhstan), East Asia (mainly China) and South Asia (mainly India, Pakistan). Annual wheat production of the world was 584 million tons. The developing regions produced 277 million tons, but consumed 338 million tons. The East Asia, mainly covered by China showed relatively high yield, in contrast to North Africa and West Asia with lower yields. Kazakhstan showed a large fluctuation in production area with low yield.

The regions in which the production amount exceeds the supply amount include the European Union, North America and other developed countries (mainly Australia). The regions requiring
more supply are Africa and West Asia. Annual worldwide import/export of wheat is 110 million tons. The developing regions are expected to increase the import from the developed regions. The main wheat exporting countries, such as U. S. A., Canada, Australia, Argentina etc., show relatively low yield of wheat under the rain-fed growing conditions.

Wheat breeding for developing regions

The International Maize and Wheat Improvement Center (CIMMYT) Bread Wheat Program has defined the mega-environments (MEs) as various agro-ecological zones in developing regions that are based on water availability, soil type, temperature regime, and associated biotic and abiotic stresses (Van Ginkel et al. 2000). Breeding objectives within each ME are selected to address the specific problems and limitations associated with wheat production in the regions. At present, 6 MEs define environments for the production of spring wheat (87 million ha), as shown in Fig. 1, and another 6 MEs for the facultative and winter wheat (43 million ha). For example, the largest ME1 represents the irrigated, low rainfall areas, and encompasses 36 million hectares. Representative areas include the Yaqui Valley (Mexico), the Gangetic Valley (India), the Indus Valley (Pakistan), and the Nile Valley (Egypt). Breeding objectives involve yield potential with durable resistance to rusts. Low rainfall environment, ME4 covers more than 12 million hectares. The breeding objective focuses on tolerance to drought associated with post-flowering and heat stress, typical of the West Asia and North Africa regions.

Table 1. Wheat supply and production (FAOSTAT, 1995-1999 average)

<table>
<thead>
<tr>
<th></th>
<th>Supply (million tons)</th>
<th>Production (million tons)</th>
<th>Area (million ha)</th>
<th>Yield (tons/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>World</strong></td>
<td>577.4</td>
<td>584.3</td>
<td>220.4</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>Developed countries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>European Union (15)</td>
<td>239.3</td>
<td>307.3</td>
<td>115.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Western Europe (excluding EU)</td>
<td>81.3</td>
<td>96.7</td>
<td>17.0</td>
<td>5.7</td>
</tr>
<tr>
<td>North America</td>
<td>1.5</td>
<td>0.9</td>
<td>0.2</td>
<td>5.6</td>
</tr>
<tr>
<td>The former USSR</td>
<td>42.0</td>
<td>90.2</td>
<td>35.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>72.9</td>
<td>66.2</td>
<td>42.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Other developed countries</td>
<td>31.0</td>
<td>31.4</td>
<td>9.3</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>Developing countries</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-Saharan and Southern Africa</td>
<td>338.1</td>
<td>277.0</td>
<td>105.2</td>
<td>2.6</td>
</tr>
<tr>
<td>West Asia/North Africa</td>
<td>11.7</td>
<td>4.6</td>
<td>2.7</td>
<td>1.7</td>
</tr>
<tr>
<td>East Asia</td>
<td>77.4</td>
<td>50.9</td>
<td>27.6</td>
<td>1.8</td>
</tr>
<tr>
<td>South Asia</td>
<td>127.4</td>
<td>112.2</td>
<td>29.9</td>
<td>3.7</td>
</tr>
<tr>
<td>Central South America</td>
<td>92.0</td>
<td>87.2</td>
<td>35.8</td>
<td>2.4</td>
</tr>
</tbody>
</table>


In particular, the developing regions that urgently require to increase and stabilize the wheat production are East Asia (China), Central Asia (Kazakhstan), South Asia (Pakistan), and South America (Brazil). Main breeding objectives focus on biotic and abiotic stresses, including pests, drought and heat.

China is one of the largest producers of wheat with 112 million tons and 29 million hectares per year. Most of the wheat production is obtained from winter wheat in the Yellow River Valley and the Low Yangtze Valley, involving the provinces of Henan, Shandong, Hebei and Jiangsu. Winter growth habit and rust resistance are required for the production in the northern part of China. In the southern part of China, one of the major constraints for stable production is incidence of Fusarium head blight (scab). Fusarium head blight causes losses in both grain yield and quality in warm and humid environments. Wheat products contaminated by Fusarium toxin severely affect the health of humans and animals. Breeding efforts for the resistance to Fusarium head blight resulted in the development of variety Sumai 3 in 1970. However, the genetic resources of immune resistance to Fusarium head blight have been not reported. Several quantitative trait loci for the resistance have been identified by using the molecular marker analysis. Recurrent selection method combined with the dominant male sterility gene successfully accelerated the development of varieties Ema1 11 and Wanmai 23. In the 1990s, Fusarium head blight spread to the cooler areas, that is, major wheat production areas of the developed world, the European Union and the North America. The northern part of Japan, Hokkaido has also suffered from the incidence of Fusarium head blight.

Wheat production of Kazakhstan has been affected by the economic crisis of the 1990s. The northern part of the Kazakhstan steppe is the main production area of 10 million hectares with an annual rainfall of 340mm. In addition, severe infection by rusts under low humidity during spring-sowing cultivation resulted in the fluctuation of the wheat production. Average grain yield shows less than 1.0 tons/ha. CIMMYT has strengthened the breeding activities for Central Asia in cooperation with the International Center of Agricultural Research in the Dry Areas (ICARDA, headquartered in Syria).

In Pakistan, main wheat production areas are Punjab and Sindh States in the Indus Valley. Wheat production is 17 million tons from 8 million hectares. Based on the CIMMYT spring wheat mega-environment classification, these areas are typical as ME1 areas. Drought and rust diseases are important constraints for the stable production.

Brazilian wheat shows a production of 2.4 million tons from an area of 1.4 million hectares from mainly three states of the southern part. These areas receive annual rainfall of more than 1500 mm. As wheat production reached 6 million tons in the 1980s, it is expected to increase further if the constraint of acid soils is overcome in the central Cerrado region. No-till cultivation has become more available for the farmers to avoid erosion of fertile soil. Rainfall during flowering time causes Fusarium head blight and pre-harvest sprouting resulting in poor grain quality.
Wheat evolution and breeding

Practical improvement of wheat requires three steps; the screening of useful genetic resources, genetic recombination, and identification of recombinants. In case genetic resources are not available within the wheat species, it is an alternative way to incorporate appropriate genes from related species through wide hybridization. This method has been used for improving resistance to pests and diseases, and strengthening tolerance to abiotic stresses.

Wheat (*Triticum aestivum* L.) is a hexaploid species, consisting of A, B and D genomes which are derived from different wild relatives. A high level of resistance to diseases and tolerance to drought has been found among the synthetic wheat lines produced from hybridization of durum wheat (*T. turgidum* L., AB genome) and goat grass (*T. tauschii* L., D genome). It is anticipated that useful genetic resources required for wheat improvement remain in the unexploited wild relatives (Mujeeb-Kazi and Hettel 1995). Wheat species show relatively high crossability with related species beyond the genus *Triticum* and the tribe Triticeae. Successes in wide hybridization have been accompanied by recent advance of tissue culture techniques. The transfer of alien genes from the genus *Agropyron*, *Thinopyrum*, *Elymus*, and *Leymus* has been attempted for wheat germplasm improvement in spite of low chromosomal recombination frequency between wheat and wild relatives. Wheat is able to successfully hybridize with maize, sorghum and pearl millet, but wheat chromosomes are preferentially eliminated from the hybrid zygotes, resulting in the production of haploid wheat embryos. Alternatively, a preliminary report from molecular approach to improving

Fig. 1. Six mega- environments for the production of spring wheats (CIMMYT)
stress tolerance in wheat shows that over-expression of transcription factors interacting with the dehydration response element has resulted in improved tolerance to drought.

Main objectives of wheat improvement in developing regions include stable and high yield, wide adaptation, and durable resistance to diseases. These agronomic traits are closely associated with wheat growing conditions. International nursery networks for testing the wheat materials are required for effective and rapid development of wheat varieties adaptable to the developing regions.

Utilization of artificially induced mutations

According to the FAO/IAEA Mutant Variety Database (Maluszynski 2001), 197 bread wheat varieties have been registered so far. Out of them, 124 and 34 varieties were reported from China and the former USSR, respectively. The agronomic traits, such as, earliness, lodging resistance, yield, disease resistance, and stress tolerance are improved by induced mutations, as shown in Table 2. Two Japanese varieties, Zenkoujikomugi in 1969 and Shirowasekomugi in 1977, were reported with modified traits of earliness and plant type, respectively.

Durum wheat has 25 registered varieties, mainly from the Mediterranean countries. Modified traits are improvement in lodging resistance and yield, but not in grain quality. Development of technologies on rapid selection of mutants at the early developmental stage is required for further utilization of induced mutations in wheat improvement. At the same time, functional analysis between genotypes and agronomic traits requires effective induction and identification of a large number of mutations.

According to the U.S. Census Bureau projections, world population will increase from the present 6.2 billion to a level of nearly 8.0 billion by the end of the next quarter century. Population of the developing regions which is 5.0 billion at present will grow at higher rates, reaching a total of about 6.8 billion, in spite of negligible increase of population in the developed regions. Demand for food security in production and supply is furthermore strengthened in the developing regions due to unfavorable growing conditions. As a global research project of wheat for food security, it should be targeted to the increase and stability of wheat yield by overcoming the environmental stresses. International collaboration network in wheat research becomes increasingly important for the international contribution to the world food security.

<table>
<thead>
<tr>
<th>Table 2. Numbers of varieties of bread wheat and durum wheat registered at FAO/IAEA Mutant Variety Database 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earliness</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Bread wheat</td>
</tr>
<tr>
<td>Durum wheat</td>
</tr>
</tbody>
</table>
References


開発途上で地域におけるコムギの品種改良の動向

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コムギは、イネ、トウモロコシ、オオムギなどの主要穀類の一つであり、世界的に広く栽培される。その半分が栽培不良環境の多い開発途上地域で生産・消費される。国際トウモロコシ・コムギ改良センター（CIMMYT、本部メキシコ）が開発したコムギ品種は、短程で非日長感受性的特性を有し、メキシコの栽培環境に類似したインド、エジプトなどの低緯度灌漑地域における生産量を飛躍的に向上させ、1970年代の「緑の革命」となる多大の成果を上げた。しかし、近年では、開発途上地域における急激な人口増加に即応するための食糧の安定的かつ持続的生産の確保が必須となっている。本報では、開発途上地域におけるコムギの生産の向上と安定化のための品種改良の動向をまとめた。

国際連合食糧農業機関の統計（FAOSTAT, 1995 ～ 1999年）によると、コムギの主産地は欧州連合（EU）、北アメリカ、旧ソビエト連邦、東アジア及び南アジアであり、総計58,430万t生産される。そのうち約半分が開発途上地域で生産される。東アジア地域では、単収が比較的高く、その生産量の99.8％が中国で生産される。一方、北アフリカ及び西アジア地域では、単収が低い。世界のコムギの輸出入量は、年間約11,000万tで、明らかに先進地域から開発途上地域の方に流れている。

今後、開発途上地域においてコムギ生産の増加・安定が期待されるのは、東アジア（中国）、中央アジア（カザフスタン）、南アジア（パキスタン）、南米（ブラジル）などであり、病虫害、乾燥、高温など高度な生産環境ストレスを克服する技術開発が重要となる。病虫害の生物学的ストレスに対する抵抗性や乾燥などの非生物学的ストレスに対する耐性を向上させるうえで、効果的な方法である。

一方、デュラムコムギ（Triticum turgidum L. ゲノムA及びB）とタルホコムギ（Triticum tauschii L. ゲノムD）からなる複合体である合成コムギ系統に高い病害抵抗性や乾燥耐性が見出されたことから、その一つであるタルホコムギの遺伝資源が有望視されている。また、植物分類学上の属を越えてコムギと交雑親和性を示す植物種も多い。耐病性に優れるAgropyron、Thinopyryn、Elymus、Leymusなどの近縁種からの遺伝子導入が積極的に試みられている。

FAO/IAEA Mutant Variety Database 2001によると、突然変異利用のコムギ品種は、パンコムギで197品種が世界で登録されている。そのうち、中国で124品種、旧ソビエト連邦で34品種が育成された。改良された農業形質としては、早熟性、多収、耐病性、短強筋など
が多い。我が国では「ゼンコウジコムギ」（1969）及び「シロワセコムギ」（1977）が育成されている。また、デュラムコムギでは強短稈の形質を中心にイタリアなどの欧州で25品種登録されている。

質疑応答
丸山：小麦の品種改良に突然変異を用いていく時にはどのようなポイントに気を付ければよろしいのでしょうか。
稲垣：一つは突然変異の目標、例えば品質、早熟性、耐倒伏性、強稈性等の目標を確信にする事です。また、そのための選抜の方法を決めなければいけないということがあります。さらに、小麦における様々な形質と遺伝子を結びつけるための材料を作るという意味でも、突然変異は極めて効果的だと思います。
奥本：小麦は異質倍数体なので、Rゲノムのライ小麦やGゲノムを持つティモシュー小麦等のように、さまざまなゲノムが利用可能だと思うですが、このような異種のゲノムの利用の将来性はどうなのでしょう。
稲垣：人類初の人工作物としてライ小麦というものがあります。このライ小麦もCIMMYTが中心になって品種改良をしております。昔の品種に比べてかなり品種改良は進んでいますが、それがなかなか受け入れられないという現状があるようです。一般論としては、野生種あるいは近縁野生種の特性を取り入れた中間素材を評価する、それを品種育成の事業のなかに持ち込むという2段階のステップが必要だと思います。日本でも世界でも野生種を一つは取り入れるのですが、それが中間素材のレベルで止まっている、もうワンステップ上げて、品種の中にまで取り込むという2段目のステップのところが長年月を要するがゆえに、それを利用して品種に結び付けるまでに至らないというところが一番のネックだと思います。そのために、現在使われているバイオテク技術であろうと、古典的な選抜技術であろうと、いかにしてそれを効率よく選抜していくかというところが重要だと思います。ひとつの例として、私がCIMMYTにいた時の共同研究者にアブドル・ムジープという人がいました。彼はデューラムコムギにDゲノムのスクワローサを交配して、合成コムギを作りました。日本でも合成コムギを作っている人がいましたが、せいぜい10とか20とかのレベルの系統です。スクワローサの持つ特性は2倍体レベルで発現したからといって6倍体の合成コムギに持ち込んで必ず発現するとは限らない。そこで、彼は世界のありとあらゆる所のスクワローサを500〜600系統を集めて、全てを交配したのです。その中から、かなり優秀な耐乾性、病害抵抗性を持つ系統が出てきました。河野先生も言われたように、人と労力がある所で、とにかく交配・選抜してみるというのは一つの方法で、それは5年間私がCIMMYTにいて、彼から学んだことのひとつだと思います。
鳥山：ヨーロッパ諸国でのコムギの収量は非常に高いですが、発展途上国では低い。これは、品種や技術以上に、登熟期間等の栽培条件が要因として大きいように思われます。発展途上国で収量レベルをさらに向上させるにはどのような方策が考えられるでしょうか。
稲垣：イギリスを例にとれば、1年のうち10ヶ月近くにわたり作物が圃場にあり、生育期間が極めて長い上に、草姿は短穂ですし、培塚管理で肥料も多投、病虫害管理も確立しています。一方、開発途上地域では中国を除くと収量が極めて低い。灌溉水が足りずに天水利用であるということ、病虫害の発生を有効に防除できないという問題があると考えられます。収量レベルを上げるには、遺伝的な改良と栽培管理の2つの方法があります。育種をやっている立場からすると、遺伝的力を高めることが必要かと思いますが、その一つとして、遠縁交雑を利用して異属や異種の遺伝資源を導入することが有効かと考えております。
SIGNIFICANCE OF NUTRIENTS UPTAKE MECHANISMS
IN CROPPING SYSTEMS

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Introduction

Management of nutrients uptake and management in cropping systems is increasing its importance. Although the concept of sustainability originated mainly from pressures of environmentalists in the developed countries, concerns on long-term viability of cropping systems have implications across all scales of farming and in all agroecological zones.

In developed countries, adoption of certain features of cropping systems from the Green Revolution era, basically depending on heavy use of chemical fertilizer, has systematically displaced local practices and knowledge, which were inherently sustainable and environmentally friendly. Nitrate contamination issues recently uncovered in north central Europe, the US and several countries in Asia were resulted from what seemed to be optimal economic fertilization practices (Fedkiw, 1991). Researchers estimate that 20% of the N that humans are putting into watersheds is consistently getting into rivers. Situation is getting even worse. In Japan, 670,000t of N fertilizer is applied annually to agricultural field, which equals to the application of 130kg N ha⁻¹ to whole agricultural field. In addition to this, 700,000t of N in animal manure is also applied mainly to agricultural fields. This heavy N application is causing nitrate contamination of ground water and watershed surrounding agro-ecosystems. In future, 690,000t of various forms of wastes from human activities is expected to be applied to agricultural field. To lessen the nitrate pollution, technologies which can improve inorganic and organic N use efficiencies based on the good understandings on N dynamics in cropping systems and N acquisition mechanisms of crops have to be developed.

In developing countries too, where arable land per capita ratio is steadily decreasing, adoption of the Green Revolution technologies is diminishing local practices and knowledge. For instance, the subsistence agriculture of the pre-chemical era efficiently sustained the N status of soils by maintaining a balance between N loss through grain harvest and N gain from biological N fixation. This was possible with less intensive cropping, adoption of rational crop rotations and intercropping systems, and use of legumes as green manure. The agriculture of the modern chemical era, however,
concentrates on maximum output but overlooks input efficiency. Likewise, the traditional less intensive wet-dry rotation of rice culture was gradually replaced by intensive continuous wetland rice culture leading to a lower available soil N pool (Kundu and Ladha, 1995). Depletion in organic carbon was also observed in field experiments conducted in Kenya in spite of fertilization at optimal rate (Smaling et al., 1997). The present challenge is to sustain soil fertility in cropping systems operating at high productivity levels.

Nutrients stresses (deficiencies and toxicities) are increasingly becoming widespread in many soils leading to low crop productivity. For example, yield potential of cropping systems on acid soils, which cover about 3950 million hectares of the earth’s surface, is restrained by deficiencies of P, Ca, Mg, and K, and toxicities of Al, Mn, and Fe (Salazar et al., 1997). Conventionally, fertilizers or soil amendments are used for mending such stresses. However, total dependence on fertilizers is neither economical nor pragmatic because of (a) the inability of many farmers to buy enough fertilizer, and (b) the capacity of many soils to fix applied nutrients into forms unavailable to plants (Sanchez and Uehara, 1980). There is also an increasing evidence to show that fertilization alone cannot sustain yields for long periods. For example, in continuous rice cropping with two to three crops grown annually, the use of fertilizer N increased with time but the yields often remained stagnant (Cassman and Pingali, 1995). This can be due to the higher requirement of fertilizer to produce the same yield, implying a decline in yield response to nutrients, and/or overuse of fertilizer, but either situation is a reason for concern. As an alternative, tailoring plants to fit the soil through genetic improvement is considered more economical than changing the soil. It is believed that farmers would more easily adopt a genotype with useful traits than crop and soil management practices that are associated with extra costs. However, the magnitude of nutrient stresses is so severe and widespread that no single remedial measure can perhaps effectively solve this problem. For example, it is estimated that as much as 8-26 million hectares of maize, at least 60% of beans in Latin America, and approximately 44% of beans in Africa are grown on severely P-deficient soils (Yan et al. 1996). Likewise, it is estimated that at least 50% of the arable land used for crop production worldwide is low in availability of one or more of the essential micronutrients for current varieties (Ruel and Bouis, 1997).

There are two approaches in research on nutrient acquisition and management in cropping systems. One approach is to analyze survival mechanisms of crops grown on nutrient-poor soils and results from such studies must be the foundation for basic process research. The other must emphasize basic research for a better understanding of the mechanisms of nutrient acquisition in cropping systems. The study methods for each approach are distinct and it is uncommon for researchers working in basic research to have the full competence needed for adaptive research, and vice versa. We believe, however, that to establish sustainable and productive cropping systems, two different but complementary strategies to be conducted in a collaborative and highly focused manner.
Evaluation of soil fertility

Most of soil fertility evaluation methods are based on the assumption that crop plants absorb nutrients already dissolved in soil solution. Crop activities to acquire nutrients from soil are not usually taken into consideration for the evaluation. This is one of the most important reason for lacking explicit methods for evaluating soil fertility in cropping systems, which is perhaps a major factor that led to over fertilization in developed countries.

While soil inorganic nitrogen(N) or NO\textsuperscript{3} or NH\textsuperscript{4} can be measured rather easily, reliability of method evaluating N mineralized from soil organic matter during growing season is not satisfactory. It is necessary to improve our understanding on the mechanism of crop plants to utilize organic forms of soil nutrients. Further efforts need to intensively explore the mechanisms of crop N acquisition before establishing a reliable soil N test.

Methods for testing soil P fertility also need further investigation. For instance, use of such tests as Bray, Mehlich, or Olsen on soils different from those for which the tests were originally developed provides inaccurate available soil P estimates. Available P measured by Olsen’s method, which uses calcium carbonate (pH 8.5) as an extractant, correlates well with P uptake. However, it gives a lower estimate of available phosphorus (P) for alkaline soils (e.g., Vertisols) and a higher estimate for acidic to neutral soils (e.g., Alfisols) (Ae et al., 1991).

It is thus nearly impossible to compare P fertility among different soil types with Olsen’s method alone. Olsen’s method is especially unsuitable to extract P well from alkaline soils that are rich in Ca-P. Crops like chickpea, when grown on alkaline soils, can dissolve less soluble Ca-P of the rhizosphere soil with organic acids exuded from its roots (Ae et al., 1991). Buckwheat known to reduce rizosphere soil pH by releasing proton from its root can also utilize alkaline rock phosphate more efficiently than maize (Bekele et al., 1983).

Truog method, which uses sulfuric acid as an extractant, underestimates the available P in acidic to neutral soils, especially when crops can utilize Fe-P or Al-P solubilized by organic chelating compounds exuded form their roots. In Andosols, for example, no linear relationship existed between soil available P measured with Truog method and P uptake by crops (Souma, 1986). In recent years, the recommended rates of P fertilizer in cropping systems in some regions are much higher than the amount of P actually needed by crops, especially because of low crop response to applied P. Soil P content in some fields of Hokkaido, for example, was so high that eroded soil particles into rivers increased P concentration of water to a critical level to cause algal boom and hypoxia (Tachibana et al., 1992). Sharpley et al. (1992) suggested that accounting for contributions of soil organic N and P to fertility was a major constraint for developing valid soil testing methods. This is especially relevant in highly weathered soils of Sahel, southern Africa, India and south America, where mineralization of organic forms may be the main mechanism by which nutrients become available to crops. Methods involving the use of ion exchange resins and iron-oxide impregnated paper strips have been shown to provide more reliable estimates of plant
available soil P (Sharpley et al., 1994) but the results need validation in a wider range of soils and cropping systems.

To establish cropping systems suitable for the soil conditions of different locations, reliable soil test for standardization of soil nutrient availability is necessary. Further understanding dynamic mechanisms of crop plant to acquire nutrients from soil would be indispensable to improve soil test for evaluating soil nutrient availability.

**Research on novel mechanisms of nutrient uptake: root exudates, cell walls, architecture**

In India, chickpea is widely grown on alkaline soils such as Vertisols or Arisols. Pigeonpea, on the other hand, is grown on acidic soils such as Alfisols or Oxisols. It has been recognized that chickpea and pigeonpea are crops less responsive to P application on those soils. A sizable fraction of the inorganic P in Vertisols is associated with Ca and this calcium-bound P (Ca-P) is considered to be a sparingly soluble compound, largely in the form of apatite, as the available P level of Vertisols as measured by Olsen’s method is generally very low. Chickpea was found to solubilize otherwise insoluble Ca-P in alkaline soil by lowering the rhizosphere pH with the excretion of citric acid (Ae et al., 1991). Weak response of pigeonpea to P application in an Alfisol field suggested that pigeonpea was able to efficiently utilize iron bound P (Fe-P). It was found that pigeonpea can acquire P from Alfisols by excretion of an organic acid, piscidic acid and its derivatives, which can specifically chelate Fe from Fe-P ligands (Ae et al., 1990). Pigeonpea later confirmed to exude significant amount of malonic and oxalic acids along with piscidic acid. Those acids were considered to release P from Fe-P and Al-P in soils of low P fertility (Otani and Ae, 1996b). Roots of P stressed white lupin are also known to excrete organic acids, which increases the availability of P. Johnson et al. (1996) reported that lateral root development was altered in P stressed lupin. Clustered tertiary roots called proteoid roots formed over 60% of the root mass on P stressed plants. The P stressed plants exuded 25 fold more citrate and malate as compared to P-sufficient plants. Ae et al.,(1996) showed that groundnut can solubilize Fe-P or Al-P with chelating capability of cell wall itself.

Researchers at CIAT, who observed promising genetic variation in P efficiency in bean germplasm, suspected that the variation might be due to a specific capacity of some of the genotypes to obtain P from recalcitrant organic matter. Such a specific adaptation was attributed to the release of phosphatases or other compounds capable of liberating P from organic complexes as reported in bean as well as other plants (Helal, 1990; Tarafdar and Jungk, 1987). Intraspecific variation in excreted phosphatase has been correlated with depletion of organic P in the rhizosphere, and presumably, P uptake (Asmar et al., 1995). Since recalcitrant soil organic materials often undergo physiochemical interactions with soil minerals, it is imperative that organic matter must be freed from those minerals, perhaps through chelation. While phosphatase itself may have ability to chelate ions, a combination of other natural chelating substances and phosphatases might release
P much faster from recalcitrant soil organic matter. Higher P uptake of pigeonpea from an Andisol of high humic substances than other crops (Otani and Ae, 1996a) seems to support this hypothesis. Studies in this direction have been limited so far.

Yan et al. (1996), however, reported that contrasting bean genotypes did not differ in their ability to mobilize P from either organic, Al, or Fe sources. This suggests that beans do not have obvious soil specificity in response to low P availability in contrasting soils. However, large seeded Andean bean genotypes such as G19833 tended to utilize Ca-P better than others. The superior ability of some genotypes to utilize Ca-P thus opens the possibility of developing bean cultivars that can be fertilized more efficiently with Ca-phosphate or rock phosphate. Lack of specific adaptation of bean to P sources can be interpreted as a positive result from the agronomic point of view, because this suggests that bean adaptation to P availability is stable across soil environments. This would make breeding for P efficiency relatively easier.

Nutrient-efficient genotypes may have better root growth and root architecture (Lynch and van Beem, 1993; Lynch and Beebe, 1995; Yan et al., 1995). Wissuwa et al. (2001) reported that an efficient rice genotype to uptake P from low available P Andosol had more vigorous root system than inefficient types. They also identified the position of genes concerning with efficiency of P uptake (Wissuwa, 1998). A vigorous, effective crop rooting system is essential for efficient nutrient acquisition, particularly for less mobile nutrients. The other general adaptive mechanisms could include better mycorrhizal symbiosis.

In highly P-depleted farms of Western Kenya, a combination of Minjingu rock phosphate at 250 kg ha\(^{-1}\) and 1.8 t ha\(^{-1}\) of Titania diversifolia, a common shrub planted in thousands of kilometers of farm boundaries raised yields by 400%. Titania apparently helps solubilize P fixed by iron oxides in Oxisols. Both Titania and rock phosphate are indigenous nutrient sources (ICRAF, 1997). Low grade Florida rock phosphate or BPL61 applied to 20 cm depth of Andosol was more effective for three years to increase dry matter production and P uptake of orchard grass and white clover than similarly applied high grade Florida rock phosphate or BPL 72 and single super phosphate. The mechanism the efficient utilization of low grad rock phosphate by those forage crops is not clear, though they suggest the involvement of AM mycorrhizae for increased dry matter production and P uptake (Kondo et al., 1997).

Pasture crops seem to have some mechanism to efficiently acquire less soluble P form the soil once pasture is established. For example, Kitagishi (1962) reported that orchard grass grown without P application on volcanic ash soil of very high P fixing capability, higher than 2500 mg P kg\(^{-1}\) soil, did not show P deficiency symptom once pasture is established. Ladino clover, however, decreased dry matter production without P application. In case of rice plant grown on an adjacent field to pasture showed severe yield reduction under no P conditions. In southern Thailand, tropical forage crops or stylosanthes, Brachiaria humidicola, and Brachiaria ruzinesis grown on a podosolic soil without P produced comparable dry matter to those grown with NPK (Hayashi, 2000, personal communication). Efficient uptake of less soluble soil P by grass plants might be one
of the important reasons for higher dry matter production of pasture in agro-pastoral systems.

With the development of less or no tillage systems, agro-pastoral system which rotates pasture and crop fields for a few years interval is becoming a practical and promising method for productive agriculture, especially in Brazil or Colombia. In this system, the productivity of pasture is increased after field crops even though no fertilizer is applied to pasture.

Alfalfa was reported to enhance soil N mineralization (Radke et al., 1988). It is suggested that some crops like flowering Chinese cabbage (Brassica campestris L, spp. Chinensis (L)) and carrot absorbed organic N directly and/or solubilized insoluble forms of soil organic N (Matsumoto et al., 1999). Johnson and Danman (1996) reported that heath plants in N-deficient habitats such as peat bogs use amino acid N to compensate for deficiency of N available in inorganic forms. In bogs, rate of soil N mineralization is among the lowest of any ecosystem, and the only source of N is precipitation. Organic N occurs as peat and in smaller quantities as amino acids. It is indicated that upland rice also can take up amino acid N (Yamagata and Ae, 1996). Further studies are necessary to determine if crop plants too can take up novel forms of nutrients besides amino acids.

Research on nitrogen uptake and nitrogen fixation of legumes

Legume crops are playing very important role in cropping systems as a suppliers of N through symbiotic N2-fixing capability. It is especially true for forage legumes as they definitely return certain amount of N to the soil. In case of grain legumes, the amount of N returning to the soil is depending on the amount of symbiotically fixed N. In case of soybean, contributions of symbiotically fixed N to the total N uptake are ranged from less than 20% to more than 80% among genotypes in Japan. As 30% of absorbed N returns to the soil as crop residues in case of soybean, net returns of N would be negative if the contribution of symbiotically fixed N was less than 70%. The soybean grain yield reduction gradually expanding in many soybean growing areas of Japan is speculated to be caused by the less active symbiotically N fixation rate.

In addition of lower symbiotically N fixation rate soybean, the efficient utilization of soil N that other plants cannot take up easily seems to be another reason of soybean grain yield reduction. The better growth of maize following soybean than continuous maize has generally been attributed to the residual effects of N fixed by soybean nodules. In an experiment conducted on an Andosol field, however, maize grown after non-nodulating soybean with and without N fertilization showed similar growth efficacy as that after nodulating soybean.

Based on a long term crop rotation experiment, Vanotti et al. (1995) speculated that growth enhancement of maize after soybean was due to stimulation of soil N mineralizing microbes by soybean, which might gradually deplete readily available soil N. However, the mechanism of soybean to mineralize microbes is not known.

Recently, it was found that ureid uptake rates of non-nodulating soybeans grown on higher yielding fields than on lower yielding fields. This result suggest the possibility of soybean to
Fig. 1  Residual effects of maize, nodulating and non-nodulating soybean on succeeding maize grain yield grown on an Andosol field with and without nitrogen fertilizer (Arihara, J., unpublished data).

directly absorb ureid from the soil. To confirm this possibility, N uptake rate of non-nodulating soybeans grown in sterilized sand culture supplied N as ureid or ammonium were compared. N uptake rate was much higher for soybean supplied with ureid than with ammonium. These results strongly suggest the possibility of direct uptake of ureid by soybean (Nohara et al., unpublished data, 2003).

Very contrasting situation is, however, widely recognized in the soybean growing area of Brazil or Paraguay. N fertility has been gradually built up with the cultivation of soybeans even though any chemical N is applied to them. With the improvement of N fertility, they can harvest considerable amount of wheat following soybean without any N fertilizer. Similarly, forage grass can vigorously grow after soybean as to feed more than 3 to 4 heads ha\(^{-1}\) of cattle without chemical N. In Brazil, efforts to improve symbiotically N fixation through the combined selection of better rhizobium strains and soybean genotypes increased the contribution of symbiotically N fixation to total N uptake to 80-90%. If they could produce 3t ha\(^{-1}\) of grain, soybean can return 30 to 40 kg of N to the soil as soybean generally need 100kg of N to produce 1t of grain. N fixation by soybean has playing important role to have brought Brazil to a giant agrarian in last 30 years especially after the introduction of soybean as a component in their cropping systems.

Recently a high yielding super-nodulation soybean, Sakukei 4, was developed (Takahashi, 2003). Sakukei 4 is derived from F5 generation of the progenies between normal soybean cultivar “Enrei” and super-nodulation soybean “En 6500”. Sakukei 4 usually forms over ten times more nodules than normal soybean Enrei both under the field and the pot conditions. N fixation rate is always more than two times higher than Enrei throughout the growth period under pot conditions.
where En 6500, parental line of Sakukei 4, showed the much lower rate (Fig. 2). Even under the field conditions, the contribution of N fixation to total N uptake in Sakukei 4, estimated from the percentage of N in ureid form to total N in plant sap water, was much higher than most of normal soybean lines during the period from flowering stage to early grain filling stage. Grain yield of Sakukei 4 increased linearly with the increase the dry matter production at the flowering stage (61 DAS) up to the level close to 5 t ha$^-1$. Grain yield of Enrei, on the other hand, showed little correlation with the dry matter production at the flowering stage. This indicated that Sakukei 4 makes it possible to increase grain yield through the increase of the vegetative growth, which is common strategy in cereals to obtain high yield.

![Graph](image)

*Fig. 2* Nitrogen fixation rate of normal soybean, Enrei, and super-nodulating soybean, Sakukei-4 (1998)

It is not difficult to increase vegetative growth even for soybean if enough amount of fertilizers especially N is supplied, however, it was extremely difficult to correlate it with the increase in grain yield. Sakukei 4, we believe, has a possibility to open up the way to the green revolution in soybeans.

As Sakukei 4 has smaller shape, dense planting with narrow row, or 30 cm in our case, and to apply some amount of N fertilizers at the time of planting is important to enhance the early vegetative growth and to increase the total dry matter production and expand areas of leaves. Close to 5 t ha$^-1$ of grain yields were obtained with 130 kg N ha$^-1$ and 220,000 plants ha$^-1$.

The applications of higher rate of N application could be well rewarded with increased grain yield in those experiments. Furthermore, it would be expected Sakukei 4 to build up N fertility of crop fields and finally reduce N application rate.

The green revolution of cereals was realized with application of N fertilizers along with new types of cereal crops responding well to increased N supply. In case of soybeans, some researchers proposed application of extremely high dose of N for higher grain production.
Harper (1999) noted that according to his knowledge there has been no report showing appearance of high yielding super- or hyper-nodulation soybeans with practical agronomic traits. He also stated that grain yield higher than 4t ha$^{-1}$ is necessary for super- or hyper-nodulation soybeans to pose the practical importance in crop production. Grain yield of Sakukei 4 was over 4t ha$^{-1}$ at highest yield plots on three years average with the grain yield close to 5t ha$^{-1}$ in the season of 2000. It seems possible to claim that Sakukei 4 is the first super nodulating soybean to have cleared the criteria proposed by Harper.

**Role of soil fauna (mycorrhizae, bacteria, nematodes, endotrophs, etc.) in nutrient balance of cropping systems**

It is well established that soil fauna play a major role in increasing nutrient availability and uptake, especially in nutrient-poor soils. N-fixing systems, including free living symbiotic or associative organisms, contribute significant amounts of fixed N to cropping systems. Rhizobia-legume systems fix N at rates in the range of 50-300 kg N ha$^{-1}$ year$^{-1}$. Cyanobacteria fix 15-25 kg N ha$^{-1}$ year$^{-1}$ and azospirillum-grass associations 10-30 kg N ha$^{-1}$ year$^{-1}$ (Ladha et al. 1992). The interaction between mineral fertilizers and N-fixing systems should be further studied towards a better integration within plant nutrition systems.

It is also indicated that enhanced AM association of crops through cultivation of mycorrhizal crops in previous season showed significant growth and yield promotion on soils of high P fixation capability (Thompson, 1991; Arihara and Karasawa, 2000). As AM inoculation is expensive and indigenous AM fungi usually dominate inoculated AM fungi, increasing indigenous AM fungi through proper cropping systems is practical way to enhance growth and P uptake of mycorrhizal crops. Soil factors such as P status, soil type, and pH, and climatic variables such as precipitation and temperature determine the growth promoting effects of AM in a cropping system. AM fungal populations and colonization of roots by AM fungi, and their contribution to P uptake was higher under soils of lower P availability. However, the effect of preceding crops on growth of following crops is different among soils even when P availability was low, thereby raising the possibility that differences in indigenous AM fungi in various soils mediate the effect of preceding crops. High soil moisture also increase colonization of AM even in soils of low population of AM spores, which eliminates effects of previous crops on AM colonization (Karasawa et al., 2000). Under water stress conditions, mycorrhizal wheat plants had greater acquisition of P and other nutrients compared to non-mycorrhizal plants (Clark and Zeto, 1996b). Similarly, mycorrhizal corn could take up more Fe in alkaline soils than non-mycorrhizal corn (Clark and Zeto 1966a,b). Further studies are, however, necessary to maximize the potential advantages from the mycorrhiza-crop symbiosis through a detailed understanding of mycorrhizal ecology in cropping systems.

Effects of cropping systems on managing harmful soil microorganisms need to be examined from now on to realize the positive benefits from nutrient cycling. Researchers at Wageningen
reported that when potato was grown as a trap crop, numbers of juvenile potato cyst nematodes decreased by 83% whereas the population of Trichodorus spp. increased by 78%. Compared to Fallow, population of Pratylenchus spp. Decreased under Tagetes patula by 78%, but increased under oats by 23%, when these crops were grown as green manure crops in autumn. Likewise, sesame and velvet bean were found to suppress root knot nematodes in Florida and Alabama.

**Research on nutrient balance and fertility in indigenous cropping systems**

The fertilizer-intensive cropping systems have evolved in only the last 30 to 40 years. To extend these into the next century, some modifications in nutrient management will be required. For this to happen, we must again look at nutrient equilibria in traditional cropping systems with particular attention to soil and crop health. For instance, studies in semi-arid tropics of India revealed that addition of pigeonpea as a sole or an intercrop in a cropping system not only helps in soil N fertility but also enables more P reserves available for subsequent crop growth (Ae et al., 1991; Arihara et al., 1991a, b). Based on studies of a seven century-old practice of Egyptian clover-rice rotation, which covers about 60-70% of the entire rice acreage in Egypt, Yanni et al. (1997) reported a unique natural endophytic association between *Rhizobium leguminosarum bv. trifoli* and rice roots. The N supplied by this rotation replaces 25-33% of the recommended rate of fertilizer application to rice but such benefit cannot be explained solely by an increased availability of fixed N through mineralization of N-rich clover crop residues. Yanni et al. (1997) found that clover-nodulating rhizobia naturally invade rice roots and achieve an internal population density of ~1.1 x 10^6 endophytes per gram fresh weight of rice roots. They reported that inoculation with two endophytic strains (E11 and E12) of *R. leguminosarum* significantly increased grain yield, harvest index and fertilizer N use efficiency of field-grown Giza 175 hybrid rice (Table 1). Similar studies

<table>
<thead>
<tr>
<th>Fertilization (kg N ha⁻¹)</th>
<th>Grain yield (t ha⁻¹)</th>
<th>Harvest Index (%)</th>
<th>Fertilizer Use efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
<td>E11</td>
<td>E12</td>
</tr>
<tr>
<td>0</td>
<td>4.3</td>
<td>6.3</td>
<td>6.2</td>
</tr>
<tr>
<td>48</td>
<td>5.8</td>
<td>7.9</td>
<td>7.0</td>
</tr>
<tr>
<td>96</td>
<td>5.4</td>
<td>7.1</td>
<td>7.9</td>
</tr>
<tr>
<td>144</td>
<td>6.4</td>
<td>7.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

LSD (0.05)
Fertilizer (N) 0.31 2.5 3.4
Inoculation (I) 0.32 1.9 4.4
N x I 0.65 3.9 8.8

Source: Yanni et al., 1997
on natural associations of endophytic diazotrophs in rice roots under rice-sesbania rotation in the Philippines are in progress (Ladha et al., 1993).

**Research on nutrient acquisition in relation to environmental quality and bioremediation of contaminated soils**

It is widely recognized that high yields resulting from the use of high doses of fertilizers in modern cropping systems have been achieved at some cost to environmental quality. In developed countries, in some places, soil nitrate concentration becomes so high that nitrate leached from agricultural field increased the nitrate concentration of groundwater more than 10ppm which is critical for human health. It is especially important for the area where groundwater is used for drinking water. It is well documented that leaching of nitrate occurs during the period between falls to spring when downward flow of water exceeds evapo-transpiration. Cultivating crops during this season is effective to prevent leaching of nitrate from the soil profile. It is interesting to note that some crops belonging to the family of *Brassicaceae* are indicated to uptake directly soil organic N, which would be beneficial for their growth under low temperature condition as mineralization rate of organic N is decreased (Matsumoto et al, 1999).

Soybean is usually cultivated in rotation with maize or other cereal crops in many countries because of their N fixing capability. However, soybean is speculated to significantly decrease nitrate concentration in soil profile compared to maize (Fig. 3). Difference in the amount of nitrate in soil profiles of 60cm between maize and soybean plots is estimated to be more than 100kg N ha$^{-1}$ when heavy dose of N fertilizer was applied (Arihara, unpublished data).

![Fig. 3 Effect of fertilizer and crop residue on pearl millet grain yield (Vationo et al., 1989)](image-url)
This surprisingly high figure suggest the possibility of soybean to be used for cleaning crops in a field of high nitrate concentration, though mechanisms involved in this phenomenon is still unclear. Dominique et al. (1997) recently reported that plants colonized with VAM fungi show a greater ability to take up soil nitrate than those that are uncolonized. Based on this observation, they reported that induced colonization of crop plants with VAM inoculum in the field could help alleviate nitrate contamination of groundwater.

Crops also vary in their ability to take up metals such as nickel from contaminated soils. Because of its rapid nickel transport rate, ryegrass and cabbage can accumulate high levels of nickel in the shoot as against maize and white clover with low influx and transport rate (Chaney et al. 1995).

**Crop residue management and its relation to fertility maintenance**

Maintaining indigenous soil fertility through judicious crop residue management is an urgent priority in tropical cropping systems. In highly productive fields, the soil nutrient supply matches the crop nutrient uptake pattern. The yield benefits from high native soil fertility are indeed difficult to replace with fertilizers. Cassman et al. (1995b) reported that hybrid rice yields in China on a soil with low native N fertility, where 245 kg fertilizer N was applied, was 2.2 t ha\(^{-1}\) less than that obtained on a soil with high native N fertility where only 54 kg fertilizer N ha\(^{-1}\) was applied. A study in Japan indicated that rice crop depends totally on the soil to meet N requirements from heading to maturity (Wada et al., 1986).

Rice is preferably grown in flooded and puddle field. This practice has been thought ideal to conserve soil N. However, a decline in productivity in paddy rice caused by soil N reduction has been noticed in several places in Asia, especially where two to three crops of rice are grown annually.

Soil organic N is continually lost through plant removal, leaching, denitrification, and ammonia volatalization. Continuous rice cropping under wetland conditions, for instance, leads to excessively reduced soil N condition, if soil N was not replenished enough by biological N fixation. The decrease in soil N through continuous rice cropping, in turn, is thought to lower available soil N pool in lowlands (Kundu and Ladha, 1995). The decline in N supplying capacity of rice fields is attributed to degradation in the quality of soil organic matter under such a water regime (Cassman and Pingali, 1995; Cassman et al., 1995).

Therefore, shifting from continuous wetland rice cropping to judiciously managed multiple cropping systems with a wet-dry rotation which includes cultivation of leguminous crops may rectify such problems.

However, even wet-dry rotation including legumes does not always conserve soil N. In Japan, more than 60% of soybean is grown on paddy field in rotation with rice and wheat or other crops. Soybean yield has been slightly but steadily declining since middle of 1980. As shown before, soybean exploits heavy amount of soil N for the production of grain of which N percentages is
generally more than 8%. Sharp reduction of mineralized soil N caused by continuous cultivation of soybean is suspected to occur in many paddy fields with wet-dry rotation. As grain legumes of good yield may exploit soil N more than rice, further amendments would be required to replenish soil N fertility.

Fertilizer-use efficiency is often low in tropical cropping systems due to the declining level of organic matter. Addition of small amounts of high-quality organic matter (a narrow C/N ratio and a low proportion of lignin) to tropical soils can substantially improve fertilizer efficiency (Snapp 1995). Nearly four decades ago, two long-term cropping studies in Kenya and Nigeria indicated that organic plus inorganic inputs sustain fertility at a higher level than the expected additive effects of either input by itself (Dennison, 1961). Nutrient effects alone do not explain the benefits derived from modest amounts of organic manure combined with inorganic fertilizers. High-quality organic matter provides readily available N, energy (carbon), and nutrients to the soil ecosystem, and helps retain mineral nutrients (N, S, micronutrients) in the soil and make them available to plants in small amounts over many years as it is mineralized. High-quality carbon and N provide substrate to support an active soil microbial community. Soil microbes are valuable not so much because they supply nutrients directly, but because they enhance the synchrony of plant nutrient demand with soil supply by reducing large pools of free nutrients (and consequent nutrient losses from leaching and denitrification). Thus microbes maintain a buffered, actively cycled nutrient supply (Snapp 1995). In addition, organic matter increases soil flora and fauna (associated with soil aggregation, improved infiltration of water and reduced soil erosion), complexes toxic Al and manganese (Mn) ions (leading to better rooting), increases the buffering capacity on low-activity clay soils, and increases water-holding capacity.

Examples of yield gains on farmers’ fields in southern Africa through inorganic/organic combinations are presented in Table 2. Often the largest gains are seen on research stations where soil fertility is already high.

On-farm gains are usually lower because of inherently low soil fertility, water deficits, and management compromises. Drastic increase of pearl millet grain yield with incorporation of crop residue was reported from the field experiment conducted in Sadore, Niger (Fig. 3, Bationo et al., 1989).

With application of crop residue alone increased grain yield from less than 0.2 t ha⁻¹ to nearly 0.8 t ha⁻¹. Crop residue applied with fertilizer increased the grain yield up to 2 t ha⁻¹ when it was about 1 t ha⁻¹ with fertilizer only.

Further research is necessary on how soil organic matter influences nutrient availability and uptake in various cropping systems. In southern Africa, agricultural intensification is often associated with the diminished availability of animal manures. As pressure on arable land rises, cropping encroaches on areas previously used for grazing, and livestock production becomes more difficult. This problem is more common in the unimodal rainfall areas of southern Africa, where the long dry season makes zero-grazing techniques difficult or impossible for smallholders, than in the bimodal rainfall areas of eastern Africa. Manure from cattle and other animals is very important for
Table 2  Examples of gains in maize yield obtained through combinations of organic and inorganic fertilizer at levels practicable on farmers’ fields in Malawi and Zimbabwe

<table>
<thead>
<tr>
<th>Organic Fertilizer</th>
<th>Inorganic fertilizer</th>
<th>Location &amp; season</th>
<th>Maize grain yield (t ha⁻¹)</th>
<th>No fertilizer</th>
<th>Organic alone</th>
<th>Inorganic alone</th>
<th>Organic+ inorganic mix</th>
<th>Yield of mix as a % of alone treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leucaena leucocephala alley cropped with maize 1.5-2.5 t/ha of Leucaena prunings applied to maize</td>
<td>30 kg N/ha applied to maize</td>
<td>Chitedze Research Station, Malawi, 1988-90</td>
<td>2. 24</td>
<td>3. 32</td>
<td>2. 72</td>
<td>3. 6</td>
<td>119</td>
<td></td>
</tr>
<tr>
<td>Pigeonpea Intercropped with maize in previous season; pigeonpea residues incorporated into the soil</td>
<td>48 kg N/ha applied to maize crop</td>
<td>Luyangwa Research Station, Malawi, 1993-95</td>
<td>0. 87</td>
<td>1. 70</td>
<td>1. 98</td>
<td>2. 31</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Cattle manure: 13-25 t/ha broadcast and plowed in before planting</td>
<td>112 kg N, 17 kg P, and 16 kg K/ha as split basal and topdress applications</td>
<td>6 communal farms, Wedza and Chinyika, Zimbabwe, 1994/95 season (a drought year)</td>
<td>0. 79</td>
<td>1. 11</td>
<td>1. 30</td>
<td>1. 93</td>
<td>160</td>
<td></td>
</tr>
</tbody>
</table>

Note: These gains are from the first cropping season after fertilizer application. Additional gains can be expected in the following seasons.

most farmers in Zimbabwe, less so in Zambia, but rarely available in Malawi (where animals are scarce). But even in the best areas, the supply (and, as important, the quality) of animal manure is inadequate to maintain soil fertility on its own.

**Nutrient acquisition and management in organic cropping systems**

Recently, there has been a tremendous interest in organic agriculture, especially in developed countries. Soil fertility research in organic cropping systems is, however, still at its infancy and
further studies are necessary to support this rapidly growing industry. For instance, research on organic onions at the University of California showed that organic farms have lower soil and plant nitrate levels even though their yields were comparable to those in conventional systems (Chaney 1996). Soil nitrate levels were similar at the beginning of the season (about 20 ppm), but by mid-June nitrate in the conventionally farmed soils increased to 76 ppm and remained significantly greater than in the organic system until the end of the season. Nitrate levels on the organic farms remained constant at about 15 ppm through the entire season. A similar pattern was found with soil ammonium. Nitrate-N in the onion roots and tops was also lower in the organic system than in the conventional system. The question is that how organic onions obtained reasonably adequate supplies of N despite a low nitrate levels in the soil and plants. The results suggest that nutrient acquisition and uptake patterns may be different in conventional and organic cropping systems. Although the pool of inorganic nutrients is small in such systems, the nutrient supply may be sufficient to support crop growth because of the continual re-supply of nutrients by microbially mediated turnover rates.

Moreover, if farmers rely on organic sources of N such as compost and cover crops for meeting the entire nutrient demands, it is important to determine how nutrient release from such materials and nutrient demands of crops can be synchronized. Synchronizing nutrient release with nutrient demand using organic residues is technically challenging. Laboratory incubation studies have shown that high-quality residues (e.g., narrow C/N ratio, low percent lignin) supplied in conjunction with low-quality residues (e.g., wide C/N ratio and/or high lignins) can provide a continuous nutrient supply, with N being released from high-quality residues first (Snapp et al., 1995). This synchrony may also be influenced by genotypic phenological traits and photothermal regimes (Ladha et al. 1993). Surface mulches in cold wet conditions, for example, increase soilborne plant disease, promote weed infestation, impede tillage implements, and alter plant nutrient
availability. Preliminary indications are that plants with high lignins, polyphenolics, and other anti-
quality factors may not release nutrients for many growing seasons, and thus these residues may be
undesirable to use as organic soil amendments (Myers et al., 1994). More research is necessary on how
to increase plant access to nutrients in such situations. Humification parameters and electrophoretic
procedures can be used to establish quality criteria of soil organic matter and to follow the
stabilization and turnover rate of organic amendments.

Pallant et al. (1997) reported that corn root systems developed more fully under low-
input/organic agriculture systems than in conventional systems. As a result, corn yields tended to
be higher on average under organic systems, especially during years under drought conditions or
under nutrient stress, because well developed root systems are more efficient in extracting available
soil water or nutrients. Moreover, the team found some of the differences between systems to be
largely significant, e.g., root density (root length/ soil volume, cm cm⁻³) under low-input/animal
systems at mid-growing were 5.51, compared to 2.99 in conventionally fertilized corn/corn systems.
It must be borne in mind, however, that increasing needs of agricultural production in developing
countries could not be met neither by “low input” schemes nor by “organic farming” only, because
crop nutrient uptake tends to far exceed nutrient application through fertilizer.

**Research on agronomic strategies to improve nutrient use efficiency in cropping systems**

Because fertilization is not realistic in many regions for economic, logistic and other reasons,
an integrated approach using germplasm efficient in nutrient acquisition and use seems appropriate.
Adoption of genotypes with higher nutrient use efficiency (NUE) by farmers is considered easier
as no additional costs are involved and no major changes in cropping systems are necessary. Also,
nutrient efficient varieties may contribute to sustainability in many other ways (Graham and Welch,
1996). They have a greater degree of disease resistance (thereby a reduced use of fungicides) due
to enhanced membrane function and cell integrity, a greater ability to develop deep roots to
penetrate subsoil in infertile soils, and a greater seedling vigor associated with higher seed yields.

NUE is defined in several ways such as efficiency of acquisition [plant nutrient content/available
nutrient] or physiological efficiency with which a nutrient is used to produce biomass [plant
biomass/plant nutrient content] or grain [grain yield/plant nutrient content]. It is also defined as
the amount of additional grain yield per unit of fertilizer applied. Efforts to improve it must be
guided by a thorough understanding of the soil and plant processes that govern NUE. For example,
an ideal and economical approach to improve NUE in acid soils might be the combination of
liming practices for neutralizing soil acidity at the surface, coupled with selection for crops more
tolerant to Al toxicity. In cropping systems where fertilizer use is already high, cost-effective
technologies that improve NUE are necessary. In cropping systems with low fertilizer use,
however, the most promising options to improve NUE are adding small amounts of high-quality
organic matter and using crop varieties with a greater NUE.
Fertilizer use efficiency in many developing countries is generally low, seldom exceeding 25-30%. Modifications in fertilization methods, use of biological resources (e.g., azolla and legumes as green manures), and genetic improvement can all help increase NUE. Although many fertilization technologies (effective formulations; split applications; specification of suitable timing, particle size, and placement methods; development of slow-release materials and nitrification inhibitors; combined use of organic and inorganic fertilizers, etc.) are long established, their acceptance and adoption by farmers is not always encouraging. Similarly, despite the knowledge that Azolla and Sesbania have high N supply potential to support higher yields, rice farmers are averse to use them extensively. Research must be initiated, therefore, to examine the causes and to explore the prospects for blending such technologies with farmer’s practices.

The deficiency of secondary- and micro-nutrients is another factor reducing N and P use efficiency and is becoming more widespread than before in cropping systems worldwide. Supply of secondary and micronutrients can improve the yield response to macronutrients considerably. In Malawi, for example, average maize yields was improved by 40% as compared with the standard N-P recommendation when the deficiencies of B, Zn, S, and K were satisfied (Kumwenda et al., 1996). Micronutrients can be included in common fertilizer blends, or applied directly as chelated powders and suspensions, but research on optimizing their supply from a cropping systems perspective has been limited. For example, the existence of a regulatory interplay between S and N acquisition has been known for long time but studies on integrating this knowledge in formulating S recommendations for various cropping systems are very few.

**Conclusion**

Sustainable crop production will obviously require enhanced flows of nutrients to crops, which in turn comprises higher amounts of nutrient reserves in soils and higher nutrient uptake and utilization by crops. Productivity of current cropping systems and protection of environmental quality cannot be sustained for long if practices such as excessive or under application of nutrients and inefficient utilization of crop residues and wastes are continued. To achieve this goal, it is necessary to quantify measurable sustainability indicators such as: levels of available nutrients, organic compounds (carbon, N, and P etc.), soil microflora and fauna, nutrients lost through runoff and leaching, and the rates of change in those variables as affected by specific nutrient management practices in cropping systems. It is not difficult to obtain those indicators with present technology. However, it is difficult to correctly evaluate the contributions of those indicators to the productivities of crops. Crops plants have recently revealed to acquire plant nutrients with different mechanisms. Soils high in Fe-P may be suitable for pigeonpea with special mechanism to utilize Fe-P. However, for crops without such a mechanism like sorghum and maize, soils high in Fe-P is undesirable. Likewise, AM population density in soil has significant meaning for mycorrhizal corps, but is meaningless for non-mycorrhizal crops. Such indicators and their responses are likely
to vary with each cropping system due to a multitude of interactions among soils and crops in diverse climates. Design and development of comprehensive nutrient management plans for various cropping systems will also require not only knowledge on plant nutrition mechanisms, but also require an integrated knowledge to understand processes occurring in various cropping systems. Research initiatives for sustainable nutrient management at the level of the cropping system must be conceived, therefore, on the basis of a holistic understanding of interactions among production, environmental, and biological components.

References


持続的作物生産におけるマメ科作物の重要性と育種への期待

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我が国では輸作は倉作を避けるためのものと捉えられがちであるが、本来は地力の向上と強く結びついたものである。昔から、輸作は生産力増大の鍵であり、畑作農業の中心技術であった。その大きな理由はマメ科作物導入による窒素供給の増大であった。...

現代の農業は化学肥料が支えていると言っても過言ではないが、それが行き過ぎて作物の吸収量を上回る量の肥料が使用されるようになって以来、周辺環境の汚染を引き起こすようになっている。農耕地から無機態窒素が地下水や周辺水系へ流出したり、リン酸濃度の高い表土が降雨後に河川に流入していることは、我が国でも確認されている。考えてみれば、作物で回収できない量の窒素やリンを農耕地に投入すれば、いつかは土壌が抱えきれなくなってどこかに流れていくのは当たり前のことである。

そのうえ、化学肥料の成分量を上回るような家畜ふん尿が家畜から排泄され、その大部分はそのまま環境中に流れ出している可能性がある。

このような循環を無視した農業は、土壌に代表される自然が甘えた農業であったように思える。工場排水による汚染はその元を絶たてコントロールできるが、農業による汚染は広い面でおこるため、それをコントロールするためには農業生産システムそのものを養分循環型に変革しなければならない。しかも、将来、確実に起こるであろう食糧不足に対処するには、作物の生産性も維持しなければならない。このため世界各地で持続型農業（Sustainable agriculture）、代替農業（Alternative agriculture）、環境保全型農業などの新しい農業システムの確立が急がれている。

そのような農業システムでは、化学肥料の投入量が減少し、一方では家畜ふん尿や都市ゴミの処理のための有機物の投入が増えていくであろうが、その場合、鍵となる技術が輪作であろうことは広く認識されている。

実際、作物根に生じている養分吸収機能を高度に活用できるような輪作を行えば、有機物を活用して化学肥料の投入量を減らしても、生産性の高い作物生産システムが構築可能なことを実証されだしている。また、この養分循環型作物生産システムとでも呼べば農業技術では、もとと化学肥料投入量の少ない熱帯地方でも、生産性を維持できるこ
とがやはり実証されつつある。

作付体系の中で作物の根の機能を活かし、養分循環を重視した高生産性の作物生産システムを作っていくには、これまでの技術の見直しも必要である。

たとえば、作物は種類によって養分吸収の生理機構が異なることが明らかになってきている現在では、作物の養分吸収機構には種間差が無いという前提で行われてきた土壌肥沃度の評価の見直しは必要である。インドの重要なマメ科作物であるヒヨコマメは、カルシウム型リン酸でも結晶化が進み、難溶性となったものを、根からクエン酸を大量に分泌することでpHを下げ、可溶化しているし、同じくインドの重要なキヤマは、根からのキレート物質分泌や根表面のキレート作用により、鉄型リン酸からリン酸をフリーにして利用していることが明らかになっている。落花生も、やはり根表面のキレート作用により、鉄型リン酸からリン酸を可溶化していることが明らかとなっている。また、これらのマメ科作物は菌根菌ともよく共生し、圃場における菌根菌の密度を高めることができる。その結果、後作物のリン酸吸収を促進し、生育と収量を大幅に向上させることも知られている。土壌の生産力を正しく評価するには、栽培される作物によって土壌養分評価法を変えることが必要であると思われる。

マメ科作物の窒素固定は窒素源とした作物生産システムでは、硝酸塩窒素の粒化が少ないこと、アメリカにおいては、磷酸鉄粉末を施用してマメ科作物の緑肥を栽培することでトウモロコシなどの生産性が大きく向上し、生産性が持続することなどが実証されたことは、施肥技術に変更を迫るものと思われる。

作物根の養分吸収機能を作物生産の中でさらに活用していくには、機能の育種的改良が重要である。最近、農業・生物系特定産業技術研究機構の作物研究所・豆類栽培生理研究室では、根粒数が非常に多い根粒超着生系統で、窒素固定能や収量が普通大豆に勝る系統の作出に成功している。わが国では、大豆の作付増加に伴い、収量の低下傾向が見られるが、この系統を用いれば収量性の持続が可能になると思われる。ブラジルやパラグアイでは、大豆が導入されることで畑作物の生産性が大きく向上している。その大きな理由として、根粒の窒素固定能の育種的改良が積極的に行われていることが上げられる。窒素固定能以外にも、作物根の機能解明はかなり進んできており、育種的改良も可能になっていると思われるが、いまだところほど行なわれていない。このような育種が、育種事業の中心になるとは考えられないが、育種家の協力なしにはできないことも事実であり、育種分野との連携が必要と考えられる。

これまで漠然と説明されてきた輸作物の能が、明確に理解できるようになりつつあり、「根の機能を活かして作物生産性を維持・向上させる」ことのできる輸作物の開発が期待される。ムギの根から分泌される鉄とのキレート物質であるムギネ酸の発見を始まり、キヤマの難溶性リン溶解機能の解明、ナタネなどの土壌有機物窒素利用機構の解明など、この分野では日本は先進的な地位にある。今後、日本におけるこの分野の研究がさらに進展し、持続的農業生産技術を我が国がリードできるようになることを期待したい。
質疑応答
江川：キマメやヒヨコマメの根のキレート作用の強さには品種間差異があるのでしょうか。
有原：あると思います。
POTATO BREEDING WITH THE USE OF
WILD GENETIC RESOURCES

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Introduction

Potato genetic resources are diverse and the wild relatives are distributed from Midwest of USA to the southern end of Chile. Climatic zones for the taxa also vary such as the coastal desert, Andean tropical highlands, and subtropical Amazonas area that should give an idea on possibility of wide environmental adaptability. There are about 200 species of the tuber-bearing Solanum, consisting of diploid to hexaploid taxa (Ross 1986).

Relatively narrow genetic diversity from landraces and a limited extent of germplasm has been employed in conventional potato breeding at the global level for resistances up to recent two decades (Watanabe 1999). While a high level of resistances, such as to potato virus X (PVX) and Y (PVY) which are single dominant inherited traits, were incorporated from wild species, only a small proportion of the existing huge germplasm collections in genebank reservoirs have been practically used (Watanabe 1999). Most wild species were under-utilized for their potential in providing highly important traits, such as resistances to biotic stress because of the lack of systematic enhancement methods with them. Furthermore, a high level of a resistance to cucumber mosaic virus (CMV), which is one the most devastating diseases for vegetable crops species worldwide (Valkonen and Watanabe 1999), was found in potato germplasm. Thus, making the potato exotic genetic resources in an usable form can be very important beyond tuber-bearing Solanum taxa such as Lycopersicon for crop genetic improvement (Watanabe et al. 1995a, c).

Introgressing such valuable resistant characters into potato varieties is particularly important for growers in developing countries as they have relatively limited resources to control pest in their Integrated Pest Management (IPM) system, even at affluent societies at developed countries, there is concern on the sustainability, and the use of resistance cultivars is the important component to avoid environmental and health risks by the over-uses of agrochemicals. Thus, solving the bottlenecks in potato breeding, with the wild genetic resources which provide resistances, is of major importance.
Constraints in conventional potato breeding

The major constraints in potato breeding have been discussed widely and the following would be the aspects to be alleviated or improved (ROSS 1986; WATANABE et al. 1995a; WATANABE 1999). 1) The genetic base of the present potato cultivars is narrow, and could be very susceptible to newly-arisen pests such as potato late blight in Ireland which resulted in the Great Irish Famine. 2) Tetraploid genetics is far more complicated than the diploid situation, what is more, outcrossing nature of the tetraploid cultivars would cause more complications in segregation. 3) The breeding objectives often involve quantitative traits with high environmental effects. 4) Interlocus interaction (epistasis) and heterozygosity are important factors, while additive components also contribute to quantitative traits. 5) Identification of individual chromosomes was very cumbersome by conventional cytogenetic methods, while monitoring recombination and introgression was very difficult by phenotypic evaluation.

Germplasm enhancement at the diploid level using haploids and 2n gametes

Landmark achievements in potato genetic improvement have occurred in the past two decades by establishing systematic germplasm enhancement methods and subsequent breeding approaches, particularly the International Potato Center (CIP) had contributed in this discipline with its international collaborators. Germplasm enhancement with diploid tuber-bearing Solanum species, including some diploid cultivated taxa has been conducted widely in many potato breeding programs (WATANABE et al. 1994a, 1995b, 1996a,b, 1999a,b,c, also reviewed in WATANABE et al. 2003). The methods alleviate some of the bottlenecks in the conventional breeding at the tetraploid level. These involve two major tools; 1) haploids from 4x cultivars and 2) 2n gametes. Haploids from tetraploids can be obtained easily by pseudogametic parthenogenesis using a haploid inducing pollinator (HERMSEN and VERDENIUS 1973), and are used to capture the valuable genes from wild or exotic germplasm. Breeding at the diploid level with disomic inheritance facilitates simultaneous selection for target resistance traits as well as some agronomic characters (ORTIZ et al. 1994; PELOQUIN et al. 1989) Gametes with a sporophytic chromosome number, that are 2n gametes, generally occur and the inheritance of the traits are simple (WATANABE and PELOQUIN 1989, 1993; WERNER and PELOQUIN 1990). Transmission of important traits from diploid breeding lines are successfully achieved by the use of the 2n gametes, especially using first division restitution 2n pollen which occurs widely and frequently in the diploid genera of tuber-bearing Solanum species (reviewed in WATANABE et al. 2004). Furthermore, the concept on the Endosperm Balance Number (EBN) greatly assisted prediction of success in interspecific and/or interploidy crosses (JOHNSTON et al. 1980).

Major achievements were made on quantitative disease and insect pest resistances using the above strategy. These were acquired from wild species and transmitted to tetraploid breeding lines
in 5-8 years via the germplasm enhancement methods (Watanabe and Watanabe 2000). Major achievements using the scheme were made on introgression of quantitative resistances to: bacterial wilt; early blight; potato tuber moth; and root-knot nematode.

**Interspecific sexual hybridization among non tuber-bearing and tuber-bearing genera**

Accumulated knowledge of reproductive biology and genetics of *Solanum* species has made it possible to use disomic tetraploid species (2 EBN) (Iwanaga et al. 1991; Watanabe et al. 1992)

![Diagram of interspecific sexual hybridization among non tuber-bearing and tuber-bearing genera](image)

**Fig. 1.** Representative scheme of the use of the diploid germplasm ploidy manipulation (Modified from Watanabe 1999)
and diploid wild species (1 EBN) including some non tuber-bearing species (WATANABE et al. 1995c), which could not be crossed directly with cultivated potato lines. Protoplast fusion is another approach to utilize distantly related taxa, however, there has not been any significant cultivar developed via using this scheme. Hereafter, we would like to state the use of sexual filial progeny in interspecific hybridization in this paper. Previous approaches including somatic hybrids required complicated ploidy manipulation and/or bridging to introgress the valuable genes from these species, while now new strategy can be made by simpler method(s).

Low profile biotechnology such as embryo rescue combined with rescue pollination (second compatible pollination) would break down major cross incompatibility barriers in many wild species which contain resistance genes of potential value in which cultivated potatoes do not have (IWANAGA et al. 1991; WATANABE et al. 1992, 1994b, 1995c).

Recent developments of the enhancement methods would make the introgression more genetically- and logistically- efficient than previous conventional breeding scheme with tetraploid wild species such as S. acaule and S. stoloniferum (WATANABE et al. 1992, 1994b) and the diploid non tuber-bearing ones such as S. brevidens (WATANABE et al. 1995c), while generalization of these methods should be exploited to achieve genotype-independent success. Alleviating problems in obtaining successful filial generations using different wild species also made an opportunity on an intriguing comparison with somatic fusion derived hybrids with respect to genetic efficiency using such species as S. brevidens.

Looking into future

Scientific knowledge on potato genetics and breeding, and the various technology on the transfer of valuable traits have promoted the use of wild genetic resources. Further enhancement of the use of these wild genetic resources in potato breeding could be made with the employment of molecular markers for selection and monitoring of introgression which was suggested about a decade ago (WATANABE 1994). A marker assisted selection on Ryvcm conferring PVY extreme resistance has been employed using SCAR markers (KASAI et al. 2000) by private sector breeding programs and such a technology can be commercialized as a tool kit with intellectual property protection (JP3047022). Relevant review in the concurrent selection markers and perspectives were reviewed in CELEBI-TOPRAK et al. (2004) and WATANABE and WATANABE (2000).

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Summary

Potato genetic resources have diversity and reside in various regions and climatic zones within the new continent. There are about two hundred species of wild relatives ranging from diploid to hexaploid. These wild species have specific individual genotypes that have high levels of specific disease and pest resistances and abiotic tolerances to harsh conditions such as to freeze and frost compared with the common tetraploid cultivars. Also, cultivated species have variation in appearance such as red, orange or purple pigmented flesh color and these pigmentation could be used as functional food materials. Wild relatives have resistances such to late blight, bacterial wilt, cyst nematodes, root-knot nematodes, viral diseases (PLRV, PVY, PVX etc), potato tuber moth etc. Many accessions of such species have been conserved in international genebanks at CIP, USA and Germany and have been characterized and employed for germplasm enhancement. These collections have systematically evaluated for specific resistance traits and yield components, and they were listed as furnishing the traits that do not exist in the cultivated genepool. Here, the germplasm enhancement scheme using such precious wild genetic resources was introduced and highlighted.

References

野生種遺伝資源の利用によるバレイショ育種

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バレイショの遺伝資源は多様であり、新大陸の異なる地域や気候帯に生息している。近縁種は2倍性から6倍性まで約200種存在する。これら野生種では、病虫害抵抗性、耐冷性や耐塩性等の適応環境への耐性の面で、既存の4倍性栽培品種のものより、はるかに優れている系統が沢山ある。また、近縁の栽培種には、赤、オレンジや紫の色素を塊茎に持ち、これらが機能食品として用いられる可能性も示されている。近縁野生種には、例えば、疫病病、青枯病、シストセンチュウ、ネコブセンチュウ、ウイルス病（PLRV、PVY、PVX等）、ジャガイモガ等病虫害への高いレベルの抵抗性が挙げられる。多数点の野生種系統が、CIP、米国及びドイツの遺伝資源銀行に保存されており、育種材料として貴重な遺伝資源である。そしてこれら系統は、体系的に多様な育種形質について評価されており、抵抗性や収量形質について、既存の栽培品種遺伝資源にない独特の特性をもっていることがデータベースによって整理されている。このような育種に適応できる近縁野生種遺伝資源を用いて、中間母本の育種や品種育成が行われているが、これらの独特の遺伝、特性や育種利用スキームについて総論した。

質疑応答
関口：国民性によってイモの色の嗜好性に関する文化的な違いのようなものがあるのでしょうか。また、イモの色が耐病性の選抜指標にならないのでしょうか。
渡邉：文化的特性というのは、一概には言えないと思います。最初持ってきた時の歴史の話を、バレイショが新大陸から旧大陸に移った時の話になると思います。400年前、その時の何がおこったかを見ないといけません。それらが一般的ではありません。原産地ベルギー、ポリビア、コロンビアなどで、目的に応じて、形が使い分けられている。アントシアニン系というのは場合によって耐虫性と関係する因子があるとも考えられしていて、バレイショの場合も関係があるようです。サツマイモの場合、アリミドキソウムの耐虫性にイモの皮の色が関係あるという報告がありますが、体系的な評価は行われておりません。
岡崎：2n pollenについて、pollenの方がFDRでできて、eggの方がSDRであるのは、バレイショに特有のことですか。バレイショには種が200種くらいあり、育種に使われているわけです。種が違えば雑種は種間交雑になりますが雑種不稔等は問題にならないので
しょうか。
渡辺：全数性配偶子が見られる場合、FDRが花粉で主体でありSDRが卵で主体であるということが双子葉植物一般において言えます。ブルーベリー、アザレア、レッドクローバー、アルファルファ等が典型としてあげられます。交雑不和合に関しては、いくつかの遺伝子的因子やEndosperm Balance Numberがあり、2倍体同士でも交雑しない、2倍体と4倍体でも交雑するという形での情報は、体系的に整理されています。交雑後代における不稔に関しては、基本的に栽培品種のバイシショは、花が咲かないものや雄性不稔がかなり多くあるということがあり、交雑後代でも花が咲かないものや雌性不稔が起きてしまいます。全く種が取れないということも多いのですが、数をこなしていくと相対的に稔性があるものが取れることもあります。
奥本：種子から作るバイシショの実用化の現状はいかがなでしょうか。また、2倍体×2倍体で、4倍体のふつうのバイシショに戻していくというお話でしたが、まったく同じ物を用いた場合と、違う2倍体同士を組合せた場合と、一般的にどちらの能力が高いのでしょうか？
渡辺：種子を使うといもが伝播する様々な病気の感染を防ぐことが可能で、きれいな種が買えなかったり作れなかったりすると発展途上国では種いもの代替技術として使われています。また、種いものの場合は、均一の遺伝子型つまりクローンだから、1個同じ品種を植えるとこれに侵す菌系がきらきら壊滅的な被害を受けることがあります。種子をつかって分離集団で違う抵抗性遺伝子を持つ個体をひとつの品種として植えると、これは平均としては量がとれます。これは作物事情が悪い地域で、非常に役立つ技術として使用されています。ただし、あくまでも種いものを使えない地域での技術になると思います。後の質問に対してですが、2倍体×2倍体で生殖交雑と2倍体は4倍体で生殖交雑を作り比較していますが、自殖弱勢が起きるメカニズムと同じようなことが問題となるようです。
VEGETABLE BREEDING IN CHINA

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Introduction

In urban areas of China, a stable supply of vegetables is required, partly because of the demand by the increasing population, and partly because of a change in eating habits. Vegetable production in greenhouses is becoming common. At the same time, the differentiation of the cultivation season is proceeding like in Japan, leading to a demand for cultivars that can be grown at different times during the year. Moreover, improvement of vegetable quality became desirable with the development of the market economy.

From 1992 to 1997, a collaborative research program for the development of disease-resistant vegetable cultivars and breeding material was carried out by the JIRCAS and the Shanghai Academy of Agricultural Sciences (SAAS). The Japanese-Chinese research team consisted of three groups engaged in research on cucumber, sweet pepper, and strawberry (SUGIYAMA et al. 1997). In this project, we developed two new F1 cultivars of cucumber and two new strawberry lines with disease resistance, high yielding ability and high quality by using the genetic resources of Japan and China. China is also a significant producer and consumer of watermelon. Here I also report the current situation in watermelon breeding in China.

1) Cucumber

After World War II, F1 cultivars of cucumber have been cultivated widely in Japan. In contrast, F1 cultivars were not commonly used in China before 1970. Even now, Chinese farmers cultivate pure-bred lines in many areas. Unlike in China, cucumbers with pistillate flowers only and lines with clusters of female flowers on each single node have been bred in Japan for many years.

The Japanese-Chinese research collaboration aimed at the development of cultivars that are suitable for the Shanghai region. One breeding target was a stick-like fruit shape without prickles, such as in cucumbers of the Huanan (south China) type. In Shanghai, popular cucumber cultivars ‘Changchunmici’ and ‘Jinyan’ display a high resistance to fusarium wilt (Xu et al, 1994a) and downy mildew (Xu et al, 1994b), respectively. However, the taste of these Huabei type (north
China) is not widely appreciated by the consumers. While cultivation in greenhouses is becoming common in the Shanghai area in spring, cucumbers are cultivated mostly in open fields during the other seasons. These plants are prone to fusarium wilt and downy mildew. Therefore, disease resistance was considered an important aim, together with high yield, early maturity, and high fruit quality.

Results

Using Japanese and Chinese genetic resources, we have bred two disease resistant cucumber cultivars, 'Hu 116' and 'Hu 119'. 'Hu 116' shows high productivity with many female flowers. It also has good fruit quality including pleasant shape, deep green skin color, and few spines (Fig. 1). The yield of 'Hu 116' is about 10 to 15 % higher than that of 'Shinkofushinari 11'. 'Hu 116' is highly resistant to Fusarium oxysporum Sch. f. sp. cucumerinum and Pseudoperonospora cubensis Rostowzew. The second cultivar, 'Hu 119', exhibits a similar degree of resistance to F. oxysporum and P. cubensis. While it produces less female flowers than 'Hu 116', its fruit quality is good, and

Fig. 1. 'Hu 116' cucumber.
our tests indicated that it might lead to more stable production. ‘Hu 116’ and ‘Hu 119’ are suitable for the semi-forcing culture distributed throughout the Shanghai area as well as in the provinces of Jhejiang, Jiangsu, Shandong, Sichuan, and others. Hu 116 is used more widely than Hu 119, because its yield is higher than ‘Hu 119’. Under the name ‘Huza 1’, Hu 116 has been cultivated on at least 3300 ha in 2001.

Future breeding targets

The main targets of future cucumber breeding in the Shanghai area are the following. 1) Adaptation to greenhouse conditions; cultivars with tolerance to high temperature and high humidity are desirable. 2) Duration of fruiting period; cultivars that produce fruit over prolonged periods help to minimize costs for large greenhouse facilities. 3) Fruit quality; deep green, hard skin, bloomless, few spins and nodules, long storage capability. Although Japanese cultivars produce high quality fruits, they are inferior to European cultivars with respect to resistance to powdery mildew, duration of the harvest period, and storage capabilities. Therefore, European cultivars are being used more frequently now in cucumber breeding in east Asia.

2) Strawberry

Although strawberry was introduced to China from Europe in the 18th century, it was cultivated only in big city suburbs. Strawberries were grown mostly in open fields. When strawberry cultivation in greenhouses became common across China in the 1980s, new cultivars adapted to forcing culture, including ‘Zaohongguang’ and ‘Shuofeng’ from the United States and

Fig. 2. ‘Shenxu 2’ strawberry.
‘Houkowase’, ‘Toyonoka’, and ‘Reiko’ from Japan, had to be imported (Morishita and Wang, 1995a). However, the need for disease resistant cultivars that were optimized for the Chinese conditions increased steadily, due to growing demand by Chinese consumers. In this situation, the Japanese-Chinese collaborative research team used genetic resources from both countries and started breeding of forcing culture-adapted cultivars with anthracnose resistance, high yield, and early fruiting.

Results

Two cultivars, ‘Shenxu 1’ and ‘Shenxu 2’, were eventually developed. They were selected as cultivars for forcing culture from crosses of ‘Belle Rouge’ X ‘Reiko’, and of ‘Kurume 49’ X ‘9418-23’, respectively. The total yield of ‘Shenxu 1’ until April is higher than that of ‘Toyonoka’ or ‘Houkowase’. The fruit is large, about 11-14 g, conic in shape with a shiny scarlet skin. The Brix value of soluble solids in the fruits ranges from 8 to 10. Since the flesh is firm and the skin is hard, this new cultivar is suitable for transportation. In China, it is important to grow cultivars that allow early harvesting, and that initiate flower buds easily without short-day or low-temperature treatments. The new strawberry cultivar ‘Shenxu No.2’ fruits extremely early; its harvesting season is earlier than that of ‘Toyonoka’. The fruit is large, about 10-11 g in weight, conic in shape with a very shiny scarlet skin color (Fig. 2). It is very sweet, moderately sour and very juicy, with a good taste. ‘Shenxu 1’ and ‘Shenxu 2’ possess a higher resistance to Colletotrichum acutatum Immonds and C. fragariae Brooks than ‘Houkowase’. Since the yield is smaller in ‘Shenxu 1’ than in ‘Shenxu 2’, it is not as widely distributed. It is estimated that ‘Shenxu 2’ was cultivated on 400 ha or more in 2001 in Shanghai, Shandong, Jhejiang, Guangdong, Guangxi, and elsewhere.

Future breeding targets

The main targets for future breeding of strawberry in the Shanghai area are shallow dormancy, pleasant aroma, high fruit set, and powdery mildew resistance.

3) Sweet pepper

In China, no sharp distinction between sweet pepper and hot pepper has been made in the past. F1 cultivars of sweet pepper were cultivated in the 1970s, but their pungent taste is different from that of Japanese sweet pepper. Today, sweet pepper cultivars of the Japanese kind and a variety of indigenous types coexist in China. To avoid the usual shortage of sweet pepper in early spring, precocious cultivars adapted to the climatic conditions of the Shanghai region are required. In this area, low temperatures and lack of sunshine during the seedling stages cause problems. Moreover, diseases, particularly aphid-transmitted virus infections, spread during the harvesting period which overlaps with the rainy season (Usugi et al, 1994; Sakata et al, 1996). Therefore the Japanese-Chinese collaborative research program aimed at the development of cultivars that reach maturity early, produce a high yield, and are resistant to viruses.
Results

Two new lines, ‘93-8’ and ‘93-16’, were produced. ‘93-8’ is precocious and its yield is about 15% higher than that of the main cultivar of the Shanghai area, ‘Jiapei 3’. Early yield and total yield of ‘93-16’ is higher than that of ‘Jiapei 3’. Fruits of ‘93-8’ and ‘93-16’ are of the bell type, are colored green, and weigh about 40 g. Both lines have higher resistance to virus (TMV-T) than ‘Jiapei 3’.

Future breeding targets

Consumers in Shanghai prefer sweet pepper with a pungent condiment. In defining future breeding targets, the preferences of consumers in the Shanghai area have to be considered. Generally, consumers prefer sweet pepper with a pungent condiment. The recent development of the demand also indicates that the ‘colored pepper’ type is desired rather than the ‘sweet pepper’ type.

4) Watermelon

In China, watermelon is distributed from Shinjan to the north and the center of the country. Apparently, watermelon cultivation in China began during the ‘Five dynasties’ period in the 10th century. China is the world leader in watermelon production. In Shanghai, the annual consumption per person reaches 25 kg. Breeding using F1 watermelons started in the 1960s in Shanghai (MORISHITA and WANG, 1995b), 40 years later than in Japan. Triploid, seedless watermelon cultivars and special cultivars or jam production have also been developed in China.

Dwarf type watermelons are developed to be grown among fruit trees (Fig. 3A) in the Science and Education Division of the Agriculture Department, Shaanxi Province (Xian). The dwarf gene is derived from the dw1 gene of American cultivars and the dw2 gene of Japanese cultivars. Shoots of dwarf watermelon do not grow longer than 2 m. Fruits weigh about 5 kg. Currently, various cultivars with different skin color and fruit shape are grown (Fig. 3B).

The Guangxi Academy of Agricultural Science is located in Nanning, and benefits from the warm climate at this. In the second half of the 1980s, seedless watermelons including ‘Gui 1-7’, ‘Kuanhsi 1-5’, and ‘Yellow Laurel Wreath’, have been developed in this laboratory using triploid plants. These cultivars are widely cultivated now (Fig. 4).

Future breeding targets

Noteworthily, ‘Jingxin 1’ was produced by the Beijing research center and Mr. Kinichi Morita in the 1980s. By this cultivar, the watermelons grown in the Beijing suburbs reached almost the same quality as Japanese watermelons. However, since ‘Jingxin 1’ is susceptible to cracking, its durability during transportation is low. Moreover, the soft taste was not appreciated by Chinese consumers. Further improvement is advancing now.

In Shanghai, the demand for small-fruited watermelons has increased quickly after the
Fig. 3. Dwarf type watermelon.
A: Watermelons are grown among grape trees. B: Various watermelons.

introduction of cultivars from Japan, South Korea, and other countries. In small-fruited watermelon, breeding targets are a thin rind and high sugar content. A fruit weight of about 3 kg is desirable. For fruit production in early spring, low-temperature tolerance and low-temperature fruit-bearing ability are advantageous. Moreover, resistance to soilborne diseases (especially *Fusarium oxysporum*) and powdery mildew are desirable.
Seedless watermelon also are becoming common in Shanghai. However, since the flesh quality is poor and the rind is too thick, the demand is low. Improvements of fruit quality are clearly required.

References

中国における野菜の育種

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中国は人口の都市への集中や改革開放後の食生活の変化や向上にともなって野菜の需要が増大しており、安定生産が強く望まれている。また施設用栽培が急増しており、日本同様に作型の分化による作型適応品種や高品質品種が求められるようになった。このような情勢から、国際農林水産業研究センターと上海市農業科学院園芸研究所において「中国における果菜類等の耐病性優良系統の育成」の共同研究（1992-1997）が実施された。

1) キュウリの育種
中国では1970年代になってからF1品種が作られ始めるようになった。日中共同プロジェクトにおいて、「満116号」と「満119号」を育成した。両品種とも半促成栽培（早熟栽培）に適したF1品種で、果実は紫華生で、つるわれ病・ベバ病に対して抵抗性である。「満116号」は、「戸 фаし1号」の名称で、2001年まで3300ha以上普及している。今後の育種目標は①施設の高温・高湿に耐える品種、②長期どりの品種、③高品質な品種などである。

2) イチゴの育種
施設栽培の普及と食生の多様化とともに、国内の促成作型に適した高品質・耐病性品種が望まれようになった。日中共同プロジェクトにおいて、「仲見1号」と「仲見2号」を育成した。「仲見1号」は促成作型に適した輸送性に優れる。「仲見2号」は促成作型向きの極早生品種で、早期収穫が多い。両品種ともC. acutatum及びC. fragraeiに抵抗性をもつ。「仲見2号」は約400ha以上普及していると推定される。今後の育種目標は、①休眠性が浅い品種、②着果性、香りがよく優れる品種、③うどんこ病抵抗性などである。

3) ピーマンの育種
ピーマンは春先は品薄となることから、早生性の優れる品種が望まれている。また、ウイルス病抵抗性品種が求められている。日中共同研究において、「9-38」と「93-16」を育成した。両系統ともウイルス病に対しては上海の主要品種「嘉配三号」より強く、TMV-Tに抵抗性をもつ。今後の育種目標は、少し辛味のある品種（微辣型）、カラーピーマン（パプリカ；彩椒）の品種が望まれている。

4) スイカの育種
スイカの生産量は世界一位で、1960年代からF1育種が求められている。陝西省農科院では、果樹間で栽培することを目的として様々な短性のスイカ品種を開発している。広西壮族自治区農科院では、1980年代後半から多くの種類のスイカ品種を作出している。今後の育種目標は、低温伸長性と低温着果性、土壌病害とうどんこ病抵抗性の品種。小玉スイカは、果皮が薄く、果肉中心部と果皮周辺部の糖度差が少ない品種が目標である。
RICE BREEDING IN WEST AFRICA - WITH SPECIAL INTEREST IN THE INTERSPECIFIC HYBRIDIZATION AND NERICAS

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Background

Rice has been more and more popular in West Africa during these 30 years. However, rice production doesn't meet its demand in many West African countries along with their steep increase in population. According to the FAO statistics in 1996, four countries had less than 20% of self-sufficiency, and the rate decreased to 47% as compared with 72% in 1960 for the whole area of West Africa. Therefore, the development and dissemination of new varieties of rice with better adaptation to the ecologies of this area is one of the important subjects in agricultural research in Africa.

Rice systems of West Africa are overviewed in Table 1. More than 80% of rice area in West Africa belongs to the humid/semi-humid climate zone (tropical rainforest, Guinea savannah, and Sudan savannah in the order of abundance of rainfall), and the share of the production in this zone exceeds 70%. Forty percent of rice area is upland and another 40% belongs to rainfed lowland ecosystem. In these ecologies, the productivity is very low (1.0 and 1.4 tons per hectare in average grain yield, respectively), because they are less intensive (typically, slash-and-burn cropping), especially depending exclusively on rainfall and ground for water source. On the other hand, relatively high productive (2.8 tons per hectare) irrigated rice system occupies only 5% of rice area, which is, though, steadily increasing by the development of inland swamps. These three rice ecosystems are most prioritized as the target of breeding activity in West Africa. Rice breeding research has been commenced in the 1920s for the improvements of grain yield and quality as well as adaptability to the environments of these ecosystems. History and up-to-date information on the rice breeding research in West Africa have been recently summarized by Tobita (2000) for reference.

Interspecific hybridization of Asian and African rice species

So-called African rice (Oryza glaberrima Steud.) is a cultivated rice species which was originated or firstly domesticated in the inland delta area of Niger River in approximately 1500 BC.
Table 1. Rice ecosystems in West Africa (after WARDA, 1999).

<table>
<thead>
<tr>
<th>Environment</th>
<th>Rice system</th>
<th>Sahre (%)</th>
<th>Area</th>
<th>Production</th>
<th>Current</th>
<th>Potential</th>
<th>Major constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humid/semihumid continuum</td>
<td>Upland</td>
<td>40</td>
<td>27</td>
<td>1.0</td>
<td>1.5-4.5</td>
<td></td>
<td>Weeds, Acidity, Blast, Drought, N-deficiency</td>
</tr>
<tr>
<td></td>
<td>Rainfed lowland</td>
<td>38</td>
<td>36</td>
<td>1.4</td>
<td>2.5-5.0</td>
<td></td>
<td>Weeds, Water control, RYMV, Fe-toxicity, N-deficiency, Drought</td>
</tr>
<tr>
<td></td>
<td>Irrigated lowland</td>
<td>5</td>
<td>10</td>
<td>2.8</td>
<td>5.0-7.0</td>
<td></td>
<td>N-deficiency, Weeds, RYMV, Fe-toxicity, Nematodes, Gall midge</td>
</tr>
<tr>
<td>Sahel</td>
<td>Irrigated lowland</td>
<td>7</td>
<td>17</td>
<td>3.5</td>
<td>5.0-8.0</td>
<td></td>
<td>N-deficiency, Cold, Salinity, Weeds, RYMV, Alkalinity</td>
</tr>
<tr>
<td>Mangrove swamp</td>
<td>4</td>
<td>5</td>
<td>2.0</td>
<td>2.5-6.0</td>
<td></td>
<td></td>
<td>Sulfate acidity, Salinity, Crabs</td>
</tr>
<tr>
<td>Deep water and floating</td>
<td>6</td>
<td>5</td>
<td>1.2</td>
<td>1.5-3.0</td>
<td></td>
<td></td>
<td>Water control, Low yielding varieties, Low fertilizer use efficiency</td>
</tr>
</tbody>
</table>

by the indigenous inhabitants of the area. It would have spread in some extent of West Africa over the latitudinal belt from Chad to Senegal. The African rice, afterwards, had been mostly replaced by Asian rice (O. sativa L.) after its arrival at the continent in around 1000 AD. However, O. glaberrima is still sure to be a valuable genetic resource for rice improvements in West Africa, because it is an indigenous species which had evolved and differentiated to adapt to the environments in this area. For that reason, from early 1990s, WARDA (West Africa Rice Development Association) has intensively characterized many accessions of African rice and found several useful traits among them, which can be possibly transferred to sativa rice (JONES et al. 1994). A number of efforts had been made in the past by European institutes for the interspecific hybridization between Asian and African rice. Unfortunately, they didn't bear any fruit because of its very low F1 seed fertility of normally less than 5%. A breakthrough came up in 1994, when WARDA’s Upland Breeding Unit has succeeded to increase the fertility through the combination of several repeats of the conventional backcrossing and the novel embryo rescue technique, followed by the anther culture procedure to fix the progeny lines genetically (JONES 1998, photo 1).

The NERICA project

In 1997, the success of the interspecific hybridization led the commencement of the project, “Africa/Asia Joint Research: Interspecific Hybridization between African and Asian Rice Species (Oryza glaberrima and Oryza sativa),” financially supported by the Government of Japan through
UNDP. This project aimed to boost rice production and improve food security of farmers and consumers in West Africa, by the development and dissemination of interspecific new varieties with good adaptation to low-input management in upland and rainfed lowland ecologies. WARDA was centered to execute and coordinate the project. Farmers and national agricultural research and extension systems (NARES) from 17 WARDA’s member countries were notably involved in this project through the PVS (participatory variety selection, see photo 2) and CBSS (community-based
seed multiplication system). Other participants, i.e., IRRI, CIAT, Cornell University (U.S.), IRD (France) and Yunnan Academy of Agricultural Sciences (China) collaborated to provide state-of-the-art technologies to the project principally in the area of molecular biology and genetics. From Japan, the University of Tokyo, JICA and JIRCAS dispatched experts and scientists to WARDA at the long-term basis, for the contribution to the fields of eco-physiology, post-harvest technology and molecular biology/physiology, respectively. In the first phase (1997-1999), the research objectives were prioritized to characterize the genetically fixed interspecific progenies, in which WAB450 lines originated from the cross of WAB56-104 (WARDA-bred upland Asian rice variety; japonica type) as a recurrent parent and CG14 (African rice variety from the Casamance Province, Senegal) as a donor parent, were exclusively used. Some of the interspecific progeny lines were selected and released as NERICA (New Rice for Africa) varieties in Guinea, Côte d’Ivoire and Nigeria in 2000, where PVS has been well accepted by NARES and farmers. So far, seven NERICA varieties, simply NERICA 1 to NERICA 7, are lined up (Table 2). On the start of the second phase of this project (2000-2003), WARDA launched the NERICA Consortium which aims to scale up the dissemination of the NERICA throughout Sub-Saharan Africa. In 2002, the NERICA Consortium was then functionally incorporated within the African Rice Initiative (ARI), which is in line with the New Partnership for Africa’s Development (NEPAD) and is an important follow-up to the Tokyo International Conference on African Development (TICAD). The ARI intends to increases in their incomes and nutritional needs and to eventually reducing rice imports through the widespread and rapid dissemination of the NERICA rice and new varieties to poor farmers in Sub-Saharan Africa.

Hereafter, this report summarizes major characteristics of the interspecific progeny lines and the NERICAs and picks up possible issues concerned with further improvements of the new rice from the view of rice breeding.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Original name</th>
</tr>
</thead>
<tbody>
<tr>
<td>NERICA 1</td>
<td>WAB450-I-B-P-38-HB</td>
</tr>
<tr>
<td>NERICA 2</td>
<td>WAB450-11-I-P31-1-HB</td>
</tr>
<tr>
<td>NERICA 3</td>
<td>WAB450-I-B-P-28-HB</td>
</tr>
<tr>
<td>NERICA 4</td>
<td>WAB450-I-B-P91-HB</td>
</tr>
<tr>
<td>NERICA 5</td>
<td>WAB450-11-I-I-P31-HB</td>
</tr>
<tr>
<td>NERICA 6</td>
<td>WAB450-I-B-P160-HB</td>
</tr>
<tr>
<td>NERICA 7</td>
<td>WAB450-I-B-P20-HB</td>
</tr>
</tbody>
</table>

**Yield and yield potential under low-input management**

Selecting a variety with high yield and yield stability in the low-input management systems is a major objective of the Interspecific Hybridization or the NERICA Project. Not a small numbers
of mass media, through papers and internet, overstate the NERICAs as to have three times higher yield potential than current varieties or good yield without any fertilizer applications. Though these are a little exaggerated, the yield potential of the interspecifics is undoubtedly more especially in the management system with low input (Fig. 1). The fixed interspecific progeny lines were tested in several experimental sites for yield under the low-input management, where solely one occasion of weeding and merely 40 kg ha\(^{-1}\) of nitrogen fertilizer were given. Out of 1200 lines of WAB450 series, a few recorded from 3.2 to 3.8 tons of grain yield as compared with 2.5 tons per hectare of IDSA 6 or WABC165, improved upland varieties. However, most of these lines decreased their yield by lodging, when cultivated under the high-input management with several occasions of weeding as necessary and 100 kg ha\(^{-1}\) of nitrogen, 40 kg ha\(^{-1}\) of phosphorus and 40 kg ha\(^{-1}\) of potassium. Three lines, namely, WAB450-11-I-P40-1-HB, WAB450-I-B-P-B6-HB and WAB450-I-B-P-38-HB or NERICA 1, showed yield stability both in low- and high-input environments. Some lines of WAB878 and WAB881 series, which are descendents from the cross of WAB181-18 (upland \textit{sativa}) as a donor parent, and CG20 and CG14 as a recurrent parent, respectively, also showed good performance in different management levels (WARDA 2000).

![Graph showing grain yield comparison between high and low input](image)

**Fig. 1** Grain yield of interspecific hybrid progenies and parents in replicated yield trials under high and low levels of management. (After WARDA 2000)

### Weed competitiveness

Weed is the most serious problem in the upland and rainfed lowland rice systems where the amount of agricultural input is limited. African rice varieties generally show early growth vigor and their broad and droopy leaves can be expected to suppress the appearance and growth of weeds by hindering the light penetration. This trait should be very advantageous to the competition with weeds during the seedling emergence and early vegetative phase of growth. On the other hand, in
the later vegetative and reproductive stages, plants are desirable to have erected leaves which enable to capture more light per unit crop area, for more photosynthesis and dry matter production (DINGKUHN et al. 1999b). Therefore, the plant type would ideally shift from the African rice type to the improved Asian rice type along with growth and development. Pursuing the change of specific leaf area (SLA) as an index of leaf erectness, some lines have been selected to show the ideal transition in plant type (JOHNSON et al. 1998, Fig. 2). In the field trial, the weed competitiveness of the selected lines was also evaluated by the biomass production of actual weeds and intercrops as imitated weeds.

![Graph A](image_url)

**Fig. 2** Changes in specific leaf area over time of WAB881-10-37-18-14-P1-HB (A) and WAB880-1-38-18-2-P2-HB (B) as compared with the parents, CG14 (■) and WAB56-104 (□). (After WARDA 2000)

**Drought resistance**

Very few studies had been available on drought resistance/tolerance in *Oryza glaberrima* before WARDA started an intensive screening of African rice accessions for the trait on the yield basis in the early 1990s. Unexpectedly, the percentage of best performers in drought-prone areas was lower in *glaberrima* accessions than that of *sativa* varieties (JONES et al. 1994). Drought tolerance in African rice has been physiologically and morphologically studied by YAMAGISHI and FUJIMURA (2001), in which more abundance of roots in *glaberrima* was observed. They also reported that some accessions showed a prompt leaf rolling and stomatal closure under drought
stress at the seedling stage, as observed also by Dingkuhn et al. (1999a). These were confirmed in the field experiment at Mbé, a hot spot of moderate drought stress in north central of Côte d'Ivoire (Tobita et al. 2001). For example, CG20, an African rice variety from Casamance and is frequently used for the interspecific hybridization next to CG14, was suggested to have the mechanisms to suppress transpiration when available soil water was limited. However, the variety did not show a deep root system which has been recognized as a typical character of drought-tolerant *sativa* upland varieties, as like Azucena and Morobérékan. Therefore, through interspecific hybridization, it is expected to develop new rice varieties with integrated mechanisms of drought tolerance, namely, both an ability to take up more water and an ability to save water under drought conditions. Further studies should be emphasized on the elucidation of the mechanisms of drought tolerance of *glaberrimas* and the NERICAs in detail, and on the establishment of a quick and reliable method for a quantitative screening of drought tolerance which applicable to the QTL analysis, for example, the use of absorbent to quantify the xylem exudation rate (Tobita et al. 2001 and 2002, photo 3).

One of the NERICA's characteristics is emphasized to be drought resistance, which was based on the yield stability in trials at drought-prone areas. It is speculated that this would be more or less attributed to the earliness, which enables them to avoid drought spells. Dingkuhn and Asch (1999) reported that, from their investigation on crop duration and phenological properties of the interspecific lines and parents, the drought avoidance of NERICAs would be an outcome of the selection process, in which the *glaberrima* trait had been preferred and conserved.

Overall performance of the interspecifics under drought stress has been evaluated at Korhogo, a hot spot in north Côte d'Ivoire with severe drought, and at Mbé, where the grain yield should be

Photo 3  A WARDA research technician installing special units for the collection of xylem sap from rice seedlings in the upland field for a drought trial at Mbé.
more than 1 and 3 tons per hectare as a criterion for resistant/tolerant lines, respectively. In the 1998 yield trial, WAB450-16-2-BC12, WAB450-5-1-BL1-DR2, WAB450-16-2-BC-2-DR2 and WAB450-11-1-BL1 were the best scores.

Adaptation to soil acidity

Acidic soils spread in the humid forest zone along the coast of the Gulf of Guinea, where the deficiency of available phosphorus is a major limiting factor for rice cultivation rather than the toxic aluminum species (SAHRAWAT et al. 1995). Breeding targets are, therefore, to develop varieties with high tolerance to P deficiency and/or with good responsiveness to the application of cheap rock phosphate fertilizers. It is reported that some interspecific hybrid progeny lines showed higher and more stable yield than Asian upland varieties on acidity-prone sites. But its physiological elucidation is not yet completed. In recent field experiments at an acidity hot spot near Man, western Côte d’Ivoire, a number of accessions of African rice were evaluated for the responsiveness to phosphorus application (TOBITA et al. 2002). It was shown that tolerance to P deficiency in CG14, a *glaberrima* parent of the current interspecifics, was not so high as compared with another *sativa* parent WAB56-104. Therefore, the good adaptability of the interspecific lines to low-P soils would have come from the trait of the Asian parent. However, among African rice, some accessions had high yield stability without P fertilization, as like IG10 from Côte d’Ivoire and Acc. 100160 from Guinea. They could be employed as a genetic resource in further interspecific hybridization for the development of varieties with higher tolerance to phosphorus deficiency.

Based on grain yield, some of NERICAs were found to respond better to the application of Mali rock phosphate and to have higher P-utilization efficiency than traditional Asian upland varieties (WARDA 2000).

Adaptation to lowland ecologies

African rice had been adapted to a wide range of ecologies from upland through hydromorphic (upland but with high water table) and lowland to flood and deep water. Some of the interspecific progeny lines from the cross of Asian and African rice, accordingly, are expected to adapt well to lowland ecologies as well as to upland ecology. As described in the next paragraph, *glaberrima* rice carries the traits of disease and pest resistances important in the lowland systems, which could be introduced to *sativa* rice through interspecific hybridization.

High yield potential of CG14, a *glaberrima* parent of the NERICA lines, was demonstrated under the hydromorphic and lowland conditions. This was analyzed to be attributed to the abundance of tillers and panicle numbers and these agronomic characters were more clearly expressed in the irrigated system of dry season. Contrary to the expectation, none of the fixed interspecific hybrid progenies (WAB450 series) were shown to have inherited the trait of panicle-
number type from CG14. Some of the interspecifics was found to have better yield under the lowland condition than Bouaké 189, a common variety in the irrigated systems of Côte d'Ivoire, although most of them were panicle-heavy type. Moreover, several interspecific lines showed vigorous initial growth also in the lowland system, which would be an advantageous trait for weed suppression especially when the direct seeding method is considered (FUTAKUCHI et al. 1998). There could be little possibility to select a superior lowland variety from the current fixed interspecific lines and NERICAs. In the Sahel Irrigated Rice Program of WARDA, based at N'Diaye near St. Louis, Senegal, fertile interspecific progenies from the several crosses of Asian lowland varieties (indica type) and African rice varieties have been successfully produced and they are currently under selection and evaluation for the adaptability to the Sahel environments (WARDA 2002).

Several numbers of *glaberrima* lines were morphologically and physiologically characterized in their submergence resistance and recovery ability (FUTAKUCHI et al. 2001). It is interesting that another opportunity to utilize African rice as a genetic source for the development of elite deep-water rice varieties was proposed.

**Resistance to diseases and pests**

Rice yellow mottle virus (RYMV) causes a major limiting disease in African rice production especially in rainfed and irrigated lowland systems. Most of the Asian lowland rice varieties introduced to Africa are susceptible to RYMV, whereas many of African rice accessions are reported to be immune to the infection of this virus (SINGH 1997). There observed a differential interaction between the isolates of RYMV and rice varieties, where three interspecific progeny lines (WAB450-9-2-13-1-HB, WAB450-B-1A1.1, and WAB450-I-B-P-65-4-1) were resistant to all isolates, at least from Danané, Gagnoa and M'bè, as well as sativa check varieties of Gigante, IR47686-15-1-1 and Morobérékan (WARDA 2001). For blast resistance, although several lines were resistant to each pathotype of *Magnaporthe grisea*, only one line (WAB450-I-B-P-152-1-1) of the interspecifics showed good vertical resistance over the sites (WARDA 2001). As mentioned in the previous section, novel interspecific crosses has been made, for instance, between TOg5681 from Nigeria or TOg7291 from Burkina Faso both *glaberrimas* with high resistance to RYMV, and *sativas* of Sahel lowland varieties like Jaya, IR64, IR31785, IR1529-680-3, etc. (MIÉZAN, personal communication).

African rice gall midge (AfRGM) is a stem feeder, which larvae feed on the growing points of rice seedlings, and cause severe crop damage and yield loss. For resistance to AfRGM, the contribution of the current interspecifics is considered to be minor, because only one (WAB450-I-B-P-181-2-1) out of hundreds of the fixed lines was resistant. However, three accessions (TOg 7176 from Mali, TOg7206 from Côte d'Ivoire and TOg7442 from Nigeria) of *glaberrima* rice show good resistance to AfRGM, so it could be possible to develop new NERICAs with use of these accessions.
as a parent. Concurrently, an intensive field screening is in progress on the fixed lines from new interspecific crosses (WAB878, WAB880 and WAB881 series) for the resistance to AfRGM in paddy at Ibadan, Nigeria (TSUNEMATSU, personal communication).

Quality of rice grains

Rice is a source of good quality of protein for human nutrition. Increasing in protein content of rice grains would assist to improve the still-low nutritive status of West Africa. Already, it is revealed that African rice has more protein in grains than Asian rice, though the intraspecific variation within *glaberrima* is high (8% to 14%). The protein content of the interspecific lines varied from 7.0 to 10.2%, though that of WAB56-104 and CG14, the *sativa* and *glaberrima* parents, was 9.1% and 8.3%, respectively. This value in CG14 was exceptionally low as compared with the average (10.8%) of *glaberrima*, so by using varieties/accessions with more grain protein as a parent, superior NERICA could be developed thorough interspecific hybridization. Although there is normally a negative relationship between the grain protein content and yield, it is worth to note that some of the interspecifics demonstrated both high protein contents and high yield stability (WATANABE et al. 1999b).

The viscosity of cooked rice was estimated for the interspecific progeny lines by use of the Brabender viscography. Variation in the viscosity among the lines was revealed to be wide and some of them were so sticky as Japanese rice, nevertheless the amyllose content of CG14 was high (WATANABE et al. 1999a). It is also notable that a few of them (for example, WAB450-11-1-2-P41-HB and WAB450-24-2-1-P28-HB) were aromatic, which is one of the most favored characters by farmers and consumers in West Africa.

Genetic and molecular biological characteristics

In 1998, WARDA has set up the Molecular Biology Laboratory with assistance of Cornell University, US, in the activity of the Upland Rice Breeding Unit. Hereinto, a basic system of the PCR-based microsatellite marker techniques was successfully introduced for the analysis of DNA polymorphism. In this lab, studies have started for tagging genes associated with agronomic characters and resistance/tolerance to biotic and abiotic limiting factors in rice systems of West Africa, prioritized to drought stress and RYMV (CADALEN et TOBITA 1999). Especially for interspecific hybrid populations, the extent of polymorphism is expected to be larger than intraspecific populations, so the use of BC1F2 or doubled haploid populations from the cross of Asian and African rice varieties would be advantageous for such analyses. Comparing the interspecific combinations between several *sativa* and *glaberrima* varieties, actually 87% (WAB56-104/CG20) to 96% (WITA9/IG10) out of 132 microsatellite markers were revealed to be polymorphic (CADALEN et al. 1999).
Quantification of the contribution of genes from CG14 is much in concern in the fixed lines of interspecific hybrid progeny. Recent analysis showed that among hundreds of the lines, allelic frequency of *glaberrima* (CG14) genome varied from 1.5% to 19% and the mode was 12%. This is plausible results caused by 5 to 6 times of backcrossing with the *sativa* parent (WAB56-104) and the selection procedure to eliminate unfavorable *glaberrima* traits, like low yield, lodging, grain shattering, etc. Graphical genotyping using one of the interspecific lines (WAB450-I-B-P-153-HB) revealed that the CG14 alleles were distributed evenly to almost all parts of the genome (WARDA 2001).

The future

The NERICA rice has been much in attention by many kinds of bodies all over the world, from governments to NGOs and from groups to individuals who are concerned about the agriculture in Africa, as a start of the World Summit for Sustainable Development (WSSD) held in Johannesburg last September. It is true that promotion of the dissemination of NERICAs into Africa is promised to make better food security of people in the continent, as the delegates agreed in the summit. However, the NERICA rice is not a finished product and needs to be improved and developed by more research.

Obviously, the second breakthrough has passed when the production of fertile progenies was successful between indica-type *sativa* and *glaberrima*. This leads to a great extension of the availability of NERICAs in high potential lowland ecologies, which is now not so significant but definitely they will have more importance in very near future. The contribution of Japanese scientists and research institutions is of more and more necessity, when the target ecology has shifted from upland to lowland, since we have many experiences and achievements, knowledge and technologies on research in paddy rice. Finally, I would like to address the potential of NERICAs, not only in Africa but also in Asia, as like their unique origin.

Acknowledgements

I shall thank to Dr. Monty Patric Jones, the founding father of NERICA, for providing me a touch with such an exciting material.

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西アフリカにおけるイネ育種
一一種間交雑育種とネリカを中心として

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現在西アフリカ地域で栽培されている稲のほとんどがアジアから導入されたアジア稲
（Oryza sativa L.）である。栽培面積の7割を占める陸稲や天水田においては生物的・非生物的要因による過酷な栽培環境と、肥料や農薬等の資材投入が多く望めないことなどから
生産性が低い。一方アフリカ稲（Oryza glaberrima Steud.）は西アフリカを中心に栽培化され
、アフリカの風土・環境に優れた適応性をもつ品種・系統も多いことから、この地域に
おける稲育種にとって貴重な遺伝資源である。この中で目立すべき形質としては、雑草競合性、耐乾性、RYMV（イネ黄斑ウィルス）抵抗性、ARGM（アフリカタマバエ）抵抗性
などがあげられる。

西アフリカ稲作開発協会（WARDA）は、特に資力に恵まれない小規模陸稲栽培農家を
対象とした粗放管理適応型品種の育成をめざし、アジア稲にアフリカ稲の優良形質を導入
すべく種間交雑育種を進めてきた。この間もっぱら評価の対象となってきたWAB450シ
リーズは、アジア稲の母本としてWAB56-104（ジャボニカ型陸稲品種）にアフリカ稲の
CG14（セネガル、カサマンス地方由来）を花粉親として得られた雑種に、今度はアジア稲
を花粉親として戻し交雑を数回繰り返すことによって固定された系統群である。収量検定
試験などを経て選抜された有望な系統は、最終的に農民参加型系統選抜（Participatory
Varietal Selection）を受け、ギニア、コートジボアール、ナイジェリアでは評価の高かった
7系統がネリカ1～7としてリリースされた。したがって現在普及しているネリカは、す
べて同じ遺伝的バックグラウンドを持っていると考えられる。種間雑種系統の主な特質は
以下のようなものである。

低投入栽培条件における高い収量性は、特に陸稲や天水田で最も望まれる形質のうちの
一つであり、WAB450シリーズで代表される種間雑種系統の大きな優良性の一つである
（ネリカが肥料なしで従来品種以上の収量をあげるという情報は明らかに大げさな誤り）。
さらに高投入栽培条件に対する適応性を併せ持つ品種としてネリカ1が選抜された。雑草
競合性に関しては、種間雑種系統のいくつかが雑草が問題となる栄養生長期初頭において、
生育の旺盛さと葉が広く垂れることにより雑草を抑え込むというアフリカ稲の特質を持つ
ことが示されている。ネリカの耐乾性はよく議論になるところではあるが、生理学的・形
態学的調査からは少なくとも栄養生长期における乾燥適応機構は見出されなかった。ネリ
カが千葉県発地域で収量安定性に優れているというのは、作期が短くなったことによる千葉県回避性であろうと推測される。穏粒のタンパク質含量が高いことから、ネリカがこの地域の人々の栄養改善に貢献することが期待されている。

質疑応答
新田：ローインプットでグラベリマの収量が下がらないというのは、具体的なデータに基づいたものなのでしょうか。
飛田：グラベリマが西アフリカの過酷な環境に既に適応しているということです。ローインプットというのは肥料もありますが、除草等も含めておりますので、そのような雑草との競合などある条件においてもそれなりの収量があるということです。もちろんグラベリマの場合、ハイインプットでも収量の絶対值は低いです。
根本：WAB450シリーズと新しいシリーズ（WAB881とWAB880）につきましても、CG14が使われておりますが、CG14がグラベリマ親に選ばれた理由というのはどの辺にあるのでしょうか。
飛田：WARDAはいろいろなグラベリマのかけあわせを試みました。しかしあうまくいったものは少なく、CG14とCG20という二つの品種でかろうじて雑種後代がとれたという結果で、この状況は今も（少なくとも陸稲育種部門においては）変わっていないのでしょうか。ですから、CG14の形質が特にグラベリマの中で優れていたということはなかったと思いますし、またこれがグラベリマの典型かといえば、そうでないと思います。
RICE BREEDING IN YUNNAN PROVINCE AND CENTRAL REGION BY THE EAST CHINA SEA OF CHINA

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Introduction

From December 1982, a joint research project had been carried out on the breeding of rice varieties with cold tolerance, blast resistance, high yield and high quality using genetic resources between the Tropical Agricultural Research Center (present Japan International Research Center for Agricultural Sciences: JIRCAS) and Yunnan Academy of Agricultural Sciences, China. This joint research had lasted for more than 14 years in 4 periods and the research program and contents had been changed little by little along with its progress. As a result, many new rice varieties adaptable to the environment of Yunnan Province have been developed and planted widely, and lots of useful knowledge had been accumulated through the research on cold tolerance and blight resistance. This project was completed in March 1997 and the process and results had been summarized by HiGASHI (2000). After the completion of this project, under the comprehensive research project titled “Development of sustainable production and utilization of major food resources in China”, JIRCAS has initiated another joint research on rice from March 1999. The research subject is called “Evaluation of plant genetic resources, development of novel breeding materials and their effective utilization” and is carried out in China National Rice Research Institute (CNRRI) in Hangzhou, Zhejiang Province, and will be finished by 2003.

The author had participated in the joint research with Yunnan Province from June 1983 to March 1985 and from the beginning for two years in the one with CNRRI. In these two places, environment for rice growing are greatly different and the targets of breeding and research are also unlike. In the joint project with Yunnan Province, I had concentrated on breeding and research for development of rice varieties with high cold tolerance adaptable to high and cool region 1500-2100m above sea level. In the one with CNRRI however, I have carried out rice breeding under hot and humid conditions in summer and research on rice sheath blight resistance which is an important character for rice cultivation in the tropical and subtropical zone.
Research on breeding and cold tolerance in Yunnan Province

1) Research on cold tolerance

In Yunnan Province, rice is planted in a wide region in a height from 76m to 2695m above sea level (Yang 1992). As the growing circumstance is so different, there is rich variation in rice genetic resources. Japonica or Indica rice is cultivated depending on the height: both Japonica and Indica rice are cultivated in regions 1450–1600m above sea level; Indica rice is cultivated in regions lower than this height and Japonica rice in those above this height. In the joint research, breeding was targeted on Japonica rice for regions of 1500–2100m. Among these regions, the weather is relatively moderate and there is nearly no worry about cool weather damage in those lower than 1800m but cool weather damage often happens in regions higher than 1800m. In Yunnan Academy of Agricultural Sciences in Kunming, the capital of Yunnan Province, the height is 1916m and the average temperature in rice growing period is below 20℃ even in July, the hottest month in a year. During the reproductive period of rice from the end of June to August, extreme low temperature is less seen but cloudiness or raining often happens and slight low

Table 1. Standard cultivars for cold tolerance and sterility percentage on cold tolerance test under natural cool temperature in 1983.

<table>
<thead>
<tr>
<th>Maturity Group</th>
<th>Variety</th>
<th>Origin</th>
<th>Evaluation*</th>
<th>Place and planting conditions of test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Standard-planting at Kunming</td>
</tr>
<tr>
<td>Early</td>
<td>Lijiang-xintuan-heigu</td>
<td>China</td>
<td>High tolerant</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Pannong 1</td>
<td>China</td>
<td>Tolerant</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Somewake</td>
<td>Japan</td>
<td>Medium</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Fujiminori</td>
<td>Japan</td>
<td>Susceptive</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Yoneshiro</td>
<td>Japan</td>
<td>Susceptive</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Towada</td>
<td>Japan</td>
<td>High susceptible</td>
<td>38</td>
</tr>
<tr>
<td>Medium</td>
<td>Kunming 217</td>
<td>China</td>
<td>Medium</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Jinjing 78-102</td>
<td>China</td>
<td>Susceptive</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Yungeng 79-635</td>
<td>China</td>
<td>Susceptive</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Todorokiwase</td>
<td>Japan</td>
<td>Susceptive</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Hidekomochi</td>
<td>Japan</td>
<td>High susceptible</td>
<td>88</td>
</tr>
<tr>
<td>Late</td>
<td>Kunming-xiaobaigu</td>
<td>China</td>
<td>High tolerant</td>
<td>11</td>
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<td></td>
<td>Banjiemang</td>
<td>China</td>
<td>High tolerant</td>
<td>5</td>
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<tr>
<td></td>
<td>Gengdiao 3</td>
<td>China</td>
<td>High tolerant</td>
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<tr>
<td></td>
<td>Yungeng 20</td>
<td>China</td>
<td>Tolerant</td>
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<td>Kunming 830</td>
<td>China</td>
<td>Tolerant</td>
<td>14</td>
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<td>Yungeng 9</td>
<td>China</td>
<td>Tolerant</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Yungeng 79-219</td>
<td>China</td>
<td>Medium</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Nipponbare</td>
<td>Japan</td>
<td>High susceptible</td>
<td>85</td>
</tr>
</tbody>
</table>

* Quotation from XION (1995)
temperature lasts. Hence it is important to breed rice variety with cold tolerance in case of cold weather damage. For this purpose, we first performed evaluation on cold tolerance in Kunming and Shuangshao (2140m above sea level), the testing field for cold weather damage. In Yunnan Province, rice is grown in the highest place in the world and existence of varieties with highly cold tolerance was expected. This was proved right by the result of the first year evaluation. In Shuangshao especially, where the highest temperature could hardly reach to 25°C, several varieties have been found to have a sterility percentage no more than 30% even under these cruel conditions, showing a prospect in cold tolerance breeding. Later, with the accumulation of experiments, the standard varieties of cold tolerant was established (Xiong et al. 1995). In the two years I stayed, it was possible to evaluate cold tolerance under natural conditions by changing the place or cultivation period to catch a natural low temperature. Nevertheless, there were cases that good weather lasted in a whole year later, so we performed evaluation using testing field with constant, cool and deep water irrigation (water temperature 19°C, water depth 30cm and 40cm) together with the natural condition method. In the evaluation under natural condition, it is difficult to specify in which growth stage the cold tolerant variety shows its tolerance. So we performed identification in different growth stages using growth cabinet. Generally Yunnan varieties with highly cold tolerance are strong to cold weather in both stages of booting and flowering. In low temperature treatment of 15°C, there was nearly no flowering in Japanese varieties whereas flowering was almost normally observed in all cold tolerant varieties of Yunnan. It is supposed that rice varieties have survived and remained that have adapted to the severe low temperature in the high cool regions of Yunnan.

As a factor concerned in the highly cold tolerance in Yunnan varieties, the length of anther, that is the number of pollen is thought to be related. Compared to Japanese varieties, Yunnan varieties tend to have long anthers and anther length is closely related to fertility percentage (Fig. 1). Accordingly, it has been proposed that anther length could be used as a morphological

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**Fig. 1.** Relationship between anther length and fertility index.
screening factor in breeding for cold tolerant varieties (WANG et al. 1988). However, in experiments with segregated generation lines of the crossing, anther length was considered to be highly related to culm length and to solve this problem between long anther and long culm/low resistance to lodging. In the practical breeding, short/medium culm and long anther parental lines have been produced with a highly cold tolerance (TANNO et al. 1996). These are used as parent materials in cold tolerance breeding in Japan.

2) Breeding of varieties with high yield and high quality

In the beginning of this joint research, most of the Yunnan cultivars were heavy-panicle plant type with long culm and big ears, and weak to lodging and poor in quality. In order to produce medium plant type of high yield and good quality, we crossbred these Yunnan cultivars with high quality Japanese cultivars of short culm and many ears. As a result, many promising lines have been produced and amongst 15 have been registered as certified varieties in Yunnan Province by year 2000. These varieties had a yield 10–20% higher than the control one and were planted in an area up to 223,000 hectare (1999), about 50% of the growing area for Japonica rice in Yunnan Province. This is a result of the harmonious cooperation among the three research groups of breeding, cold tolerance and blast resistance that compose the joint research team and of the rich manpower and budget of Yunnan Academy of Agricultural Sciences and JIRCAS.

![Graph](image)

Fig. 2. Transition of planted area of cultivars developed by the Japan-China joint team and average yield of Yunnan province (quoted from ISE et al. 1999).
Research on breeding and sheath blight resistance in central region by the East China Sea

1) Breeding of stable and high yield Japonica rice

In Zhejiang Province where CNRRI locates and the neighbor coast Jiangsu Province and Shanghai City, the situation of rice cropping is somewhat different from that in other provinces of central and southern part of China. The planting area ratio for Japonica rice is as high as 40% in Zhejiang Province, 60% in Jiangsu Province and almost 100% in Shanghai City. In CNRRI, breeding and research staff for normal Indica and hybrid Indica rice was rich, but they for Japonica had been poor. In the joint research project, so we used Japonica as the major subject for breeding and research. To understand the properties and growing situations of cultivars planted recently in China and Japan, we have investigated the growing properties and yields of them including Indica. In Zhejiang Province and its vicinities, there are two types for rice cultivation: double cropping (early-season and late-season cultivation) planted twice a year and single cropping (medium-season cultivation) cultivated once a year and cultivars for each cropping type are different. For early-season cultivation, the early-season Indica is grown and for medium- and late-season cultivation, Japonica and medium- or late-season Indica are planted. Table 2 shows the growths and yields of typical Japanese and Chinese cultivars in single cropping. The medium-season Japonica “Wuyungeng 7”, a new cultivar produced recently, has many grains per panicle in spite of a short panicle and rather high grain density, and “Xiushui 11” has panicles similar to those of Japonica varieties with moderate numbers of grain per panicle and grain density. In addition to these two ones, other Chinese cultivars also have a heavy 1000 grain weight of brown rice. It seems to show that high yield breeding in China tends to depend on the increase of grain weight, but the heavy grain and high grain density there is the fear to bring about the decrease of yield caused by

<table>
<thead>
<tr>
<th>Year</th>
<th>Cultivar</th>
<th>Origin, Variety group*</th>
<th>Heading date</th>
<th>Maturity date</th>
<th>Culm length (cm)</th>
<th>Panicle length (cm)</th>
<th>Panicles m²</th>
<th>Spikelets /panicle</th>
<th>Grain yield (kg/a)</th>
<th>1000 grain weight (g)</th>
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<tr>
<td>1999</td>
<td>Akihikari</td>
<td>Japan, J</td>
<td>8.02</td>
<td>9.18</td>
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<td>20.0</td>
<td>308</td>
<td>93</td>
<td>52.4</td>
<td>22.9</td>
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<td>You 1 66</td>
<td>China, IH</td>
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<td>92</td>
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<td>219</td>
<td>156</td>
<td>50.6</td>
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<td>China, J</td>
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<td>9.30</td>
<td>87</td>
<td>16.1</td>
<td>260</td>
<td>129</td>
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<td>China, J</td>
<td>9.06</td>
<td>10.13</td>
<td>87</td>
<td>20.0</td>
<td>266</td>
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<td>84</td>
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<td>375</td>
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<td>47.2</td>
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<td>9.08</td>
<td>82</td>
<td>23.5</td>
<td>308</td>
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<td>59.9</td>
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<td>9.30</td>
<td>103</td>
<td>25.6</td>
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<td>350</td>
<td>86</td>
<td>56.5</td>
<td>24.4</td>
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</tbody>
</table>

* J means Japonica rice and IH means Indica hybrid rice.
the lowering of ripening. Therefore, the joint research team will develop new materials of stable and high yield through improving ripening by to cross the recent cultivars of China with Japanese cultivars with good ripening characteristics.

2) Research on sheath blight resistance

In Hangzhou and the surroundings, the highest temperature is often over 35°C in addition is humid in summer, and sheath blight disease abundantly arises. In the late-season cultivation in 1999, most of Japanese cultivar in yield trial field had caught the disease and withered and it became important to produce varieties resistant to sheath blight disease. So we have carried out screening and genetic analysis for resistant materials. In Japan, except only a few reports, it has been considered that there is no genetic difference among varieties about sheath blight resistance, and so far there was nearly no breeding on resistance to this disease. In China nevertheless, there are a few reports (XHA 1987, XUE et al 1990) concerning the difference of sheath blight resistance among different varieties. In Japan too, WASANO et al (1983, 1985, 1986) have reported the genetic difference among varieties and selection effects for high resistance to this disease.

In 2000, in testing field of CNRRI, using the syringe inoculation method by WASANO et al (1983) and the direct spraying one of Rhizoctonia solani cultured on medium mixed with rice hull and wheat bran which is mostly popular method, we have investigated the resistance among different varieties which were known to have different resistance to sheath blight disease. The result showed clear difference among varieties and their resistance was almost the same as reported before. Besides, consistent results have been obtained between the two inoculation methods. Using syringe inoculation method, many varieties have been investigated and they showed a wide range of resistance from strong to weak and numerous strong varieties have been found among those of Chinese varieties. It was interesting that strong varieties were also found in early-heading varieties. This result overturned the common view that sheath blight resistance is dependent on heading and that the later heading is more resistant than early heading. Quantitative trait loci (QTL) analysis has been performed in double haploid (DH) lines of the cross between an Indica cultivar (Zhai Ye Qing 8) and a Japonica type line (Jing Xi 17) using syringe inoculation method. Of the parents, “Zhai Ye Qing 8” had a medium resistance and “Jing Xi 17” had a weak one. In the DH lines however, they showed a resistance in a wide range from resistant to susceptible and there were lines even stronger than “Zhai Ye Qing 8”, the parent with resistance (Fig. 3). In QTL analysis using MAPMARKER／QTL, four QTLs were identified on No.2 (LOD score 2.58, percentage of variance explained 11.2%, the same as follows), No.3 (2.43, 10.5%), No.7 (4.34, 15.5%) and No.11 (2.75, 9.5%) chromosomes. Among the four QTLs, the former three are originated in “Zhai Ye Qing 8” and the last one on chromosome 11 is derived from “Jing Xi 17”. In the experiment performed in Hainan Island in the spring of 2001, a similar result has been obtained but the QTL on chromosome 11 was not found (Table 3). In CNRRI, we have investigated the relation between sheath blight resistance and culm length and heading date. It was found that the correlation
coefficient with culm length was $-0.397$ (significant in 1% level) and $-0.179$ with heading date (significant in 5% level), showing a tendency of higher resistance in rice with longer culm and later heading. In QTL analysis for culm length and heading date, QTLs were identified on No.3 and No.8 chromosomes for the former and on No.8 and No.10 chromosomes for the latter. The QTL for culm length on chromosome 3 was on the same locus as that for sheath blight resistance (Fig. 4). However, this result is considered to have no great influence on breeding of sheath blight resistant lines of early-season with short culm due to the following findings: the correlation coefficients between sheath blight resistance and culm length and heading date are not so large; other QTL concerning sheath blight resistance exists besides the one on chromosome 3 and they are no linkage between QTLs of culm length and heading date. At present breeding on sheath

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**Table 3. Biometrical parameters of QTLs for sheath blight resistance in ZYQ8/JX17 DH population.**

<table>
<thead>
<tr>
<th>Place</th>
<th>QTL</th>
<th>Chromosomes</th>
<th>Marker interval</th>
<th>LOD score</th>
<th>Variance explained (%)</th>
<th>Additive effect</th>
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<td>Hangzhou</td>
<td>qSBR-2</td>
<td>2</td>
<td>RG171-G243A</td>
<td>2.58</td>
<td>11.2</td>
<td>14.502</td>
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<td></td>
<td>qSBR-3</td>
<td>3</td>
<td>G249-G164</td>
<td>2.43</td>
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<td></td>
<td>qSBR-7</td>
<td>7</td>
<td>RG511-TCT122</td>
<td>4.34</td>
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<td>18.808</td>
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<tr>
<td></td>
<td>qSBR-11</td>
<td>11</td>
<td>CT224-CT44</td>
<td>2.75</td>
<td>9.5</td>
<td>-13.383</td>
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<tr>
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<td>qSBR-2</td>
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<td>10.0</td>
<td>10.115</td>
</tr>
<tr>
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<td>RG511-TCT122</td>
<td>3.93</td>
<td>16.7</td>
<td>14.482</td>
</tr>
</tbody>
</table>
Fig. 4. QTL map for sheath blight response, heading date, culm length, and panicle number per plant in the analysis of Hangzhou data. 

blight resistance is being performed in CNRRI using those resistant materials found in all these experiments.

Acknowledgment

This work was supported by many persons, rice breeders, researchers other than rice breeding, research managers and administrative officials in Japan and China. I thank them for their warm support and cooperation. Especially I thank the persons concerned the Yunnan Academy of Agricultural Sciences and China National Rice Research Institute.

References


中国雲南および華中におけるイネ育種

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熱帯農業研究センター及び国際農林水産業研究センターは中国雲南省および華中（東シナ海沿いの中央部地域）においてイネの育種について共同研究を行った。雲南省では、標高1,500～2,100m 地帯のジャボニカ水稲を研究対象とした。この範囲の稲作地域では、1,800m 近辺からの高地で頻繁に冷害が発生する。このため、耐冷性は最重要形質の一つであり、自然の冷温を利用して耐冷性の検定を行い、雲南省品種の中から高度耐冷性品種を見出す。これらは概して耐長が長く、また、交雑後代を用いた実験で耐長が長い品種であるので、耐長による耐冷性選抜の有効性を指摘した。耐長が長いものは長程で耐倒伏性に不利であるという関係は、その後、短稈の耐冷性中間母本の育成により打破された。

新品种の開発では、長稈大穂で倒伏に弱く品質が不良であった雲南省品種を日本品種との交配により、中間型で多収・良質に改良し、2000年までに15系統が雲南省の認定品種として登録された。これら品種は対象品種について10～20％の増収を示し、栽培普及面積は22.3万ha（1999年）で省内ジャボニカ栽培面積の約50％を占めるに至った。

華中の浙江省、江蘇省、上海市は、中国中南部の他の省とは稲作の様相が少し異なり、栽培面積に占めるジャボニカの比率が高い。また、華中の夏季は高温・多湿で紋枯病の発生が多い。このため、ジャボニカの多収性育種及び紋枯病に重点をおき研究を進めた。最近の中国品種は、粒重を重くすることにより多収を実現しており、育種方針として、粒重型の中国品種に日本品種を交配し、登熟性を向上させることなどにより安定・多収の新品種素材を開発することとした。

紋枯病について、注射器接種法（Wasanoら1983）を用いて抵抗性素材のスクリーニングと遺伝的解析を実施した。検定材料は強～弱に広く分布し、中国品種等に抵抗性強の品種が多数見いただされた。紋枯病抵抗性は出穂の早晩に左右され早生ほど弱く晚生ほど強いという説を覆す結果も得られた。中及びやや弱の抵抗性を示す日印交雑（挙葉青8号／京系17）のDH系統群を検定したところ、DH系統は強～弱まで広く分布し、強い方の親よりも強い系統があった。QTL解析の結果、第2、第3、第7、第11染色体上にQTLが検出された。農業形質との関係において、稈長が長いほど、出穂期が遅いほど抵抗性である傾向を認めたが、その関係は強くなく、早生・短稈の紋枯病抵抗性系統の育成は困難でないと考えられた。
質疑応答
長戸：雲南の品種が持っている強い耐冷性の遺伝子を日本の育種に利用する計画はないのですか？
國廣：宮城県の古川農業試験場とか、東北農業試験場でそういう試みがなされまして、耐冷性素材ができています。ただ、それが、雲南の耐冷性素材（耐冷性遺伝子）に由来するものであるかどうかはまだ調べられていないと思います。
総合討論

座長 丸山清明（作物研究所）

座長：河野先生の特別講演と8名の先生方に、「作物研究の海外における動向と突然変異」ということでお話いただきました。それに関する総合討論を行いたいと思います。河野先生には、キャッサバの育種のご経験、昆虫解薬時代のご経験の話から、国際協力、遺伝資源についていろいろお話いただきましたが、残念ながら本日は所用でこの席にいらっしゃいません。わたしも、先生の「自殺する種子—遺伝資源は誰のもの」という著書を読みまして、いっしょに議論させていただきたいんですが残念です。多くの先生方は育種に関わるお話しを、あとの方では、栽培・生産についてもお話いただきました。また、地域も、南米、アフリカ、東南アジアからインド、中国と、世界中あらゆるところが話題に上がりました。全体に共通するものとして、遺伝資源が多く話題になりました。一方、「作物研究の海外における動向と突然変異」というタイトルなくで、突然変異についての話は比較的少なかったと思います。総合討論では質問時間の少なかった先生方もいらっしゃいましたので、まず追加の質問をお受けすることにして、そのあと、今後の遺伝資源どのように利用していくか、突然変異何を期待するか、あるいは、海外の作物研究から日本が学ぶべきこと、あるいは、日本から海外の作物研究にどのような寄与ができるか、この4点を中心に講師の方々、会場の皆様とのやりとりで議論を進めたいと思います。まず、ご質問からお受けしたいと思います。

天野：世界的に見て、ジャポニカタイプの粘りのあるお米というのは一般庶民の好みからいえば、どのように扱われているでしょうか。

井摂：マレーシアで試食してもらったところ、コシヒカリがまったく否定され、粘りのある米は受け入れられないようでした。しかし、フィリピンでは陸稲でジャポニカ（トロピカルジャポニカ）というものがおりまして、その価格の方がむしろ水稲よりも高く、地元の人に聞いた感じからすると、コシヒカリのような味を受け入れる素地はあると思います。

飛田：アフリカには、（インディカとジャポニカの）両方あると思います。もっとと陸稲の方はジャポニカです。農家は結構受け入れていると思いますが、都市部では輸入米が結構食べられています、それはほとんどインディカ米です。ちょっとレストランでも、出てくるお米は粘りのない米が多いです。

鳥山：エジプトではインディカとジャポニカがありますが、インディカは非常に少ないです。彼らはジャポニカを炒めてから料理します。すると粘りがなくなりバラバラのインディカと同じようにさばけて、しかも口の中に入れると1粒1粒に粘りがでます。それが一番うまいというような表現をエジプト人はしていました。

座長：台湾では、かつてのインディカがいまはほとんどジャポニカに代わっています。はしと茶碗で食べるなら「粘る、光る、冷えても柔らかい」ジャポニカ、中でもコシヒカリ
の気出しました。それをさらに上に行く低アミロース品種の育種が行われています。インドのベンガル川で「金持ちが食べるお米」を食べさせていただきましたが、出されたお米はコシヒカリのようなお米でした。単品で食べる時には、やっぱりそういうものも増えてくるのではないかと思います。中国でもジャポニカの割合が増えており、インディカのような、いわゆる高アミロース品種は減ってくるのではないかと考えています。

鳥山：グラビリマには早朝開花性があります。エジプト南部やスーダンあたりでは夏の高温時期に開花する時に不稔を回避するために非常に重要だと考えられます。ネリカ米の中にその特性が残っているなら、非常に高温で日射も強くイネの生育に不適なところでも栽培が可能と思われますが、いかがでしょうか。

飛田：WARDA ではこの形質についての調査はまだ始まっていないと思います。非常に興味があるところです。ネリカ米は研究材料として日本にも入ってきていますので、是非そういう方向での研究が進めばいいかと思います。

鳥山：先ほどの穂型はイタリアのパリラという品種と形が良く似ていますが、パリラとの関係があるでしょうか。

國廣：中国で交配親にパリラをたくさん使ったお話を聞いておりますけど、先ほどの示した材料に使われているかわかりません。着粒が密な穂型はインディカとジャポニカの交配後代から出てくることがあるということです。

江川：根粒をたくさんつける大豆の突然変異体はエンレイへの EMS 処理で得られたと聞いておりますが、根粒以外の形質の突然変異体は単離されたのでしょうか。

有原：あの系統は EN6500 というエンレイからの根粒超着生突然変異系統をもう一回エンレイと交配したもののが後代で、私たちの研究室では EMS 処理はやっておりません。EN6500 は非常に生育量の小さい系統で、作りにくい系統だったのですが、生育のいい株を残しているものですから、最近ではいろいろな欠点がなくなってきたのか、まあまあの生育をするようになってきました。根粒着生以外の突然変異もおこっていたのだろうと考えています。

山口：開発途上国地域での耐性病の育種目標には、日本では非常に問題になっている萎縮する土壌伝染性病害が入っていなかったかと思うんですけど、その辺に関する情報はありませんでしょうか。

稻垣：萎縮病は、土壌伝染性ですから病害発源土壌に栽培させざるを得ない場合には問題になるかもしれませんが、開発途上国の場合は問題になる土壌以外の場所で栽培するという対処をしています。一般的には、土壌病以外の病気、特にさび病や、温暖湿潤地域では赤カビ病の方が、重要と考えられています。

岡：パプリカは日本でも少し増えていますが、価段もそう安くないと思います。中国でも消費が増えてきそうですが、高収入の層のみが消費しているのでしょうか。あるいは中国人は食に関心が高くてそういった新しいものに皆が目を向けるということなのでしょうか。

杉山：日本人や香港人を含めた所得の高い層が購入していると考えています。高級レストランでは購入していると思います。
座長：IRRIの育種において、突然変異に対して何か期待されているのか、あるいはどういう位置付けになっているのでしょうか。

井邊：正直申しましょうと、IRRIでの突然変異の取り組みは、私の知っている範囲ではあまりありません、膨大な遺伝資源があり、おかつそれを評価するシステムとマンパワーが整っているために、その利用が非常にうまく行っていたので、突然変異まで利用する必要はなかったことかもしれませんが、将来的には、日本でやられたように品質面等で突然変異の利用がある程度進むかもしれないと思います。

天野：從来、IRRI、IITA、CYMMITのような国際農業研究所は、突然変異を利用しようということ、方向性を持ってしまっていませんでした。ただ、最近は突然変異を利用した遺伝子単離が分子遺伝学者によって進行し始めているということです。その時に得られた突然変異体が育種の担当者に回されるという情報もIRRIでは聞きました。

永富：正確に言えば突然変異ということは、花粉に放射線を照射することにより種属間の不和合性を打破する技術があります。既にトマトやサツナで成功しており、この手法他の遺伝資源の利用に使うことも可能であろうと思います。

天野：IAEAのコムギの突然育種に関するデータベースについてですが、実はこういうデータベースは国によっては信頼性が疑われる場合があります、また、間接利用つまり交配利用の場合は、育種の担当者は突然変異系統を単なる遺伝資源のひととし解釈し、突然変異品種として認識されていない場合があります。ですからデータベース利用には多少注意が必要です。

稲垣：確かにこのデータはそれぞれの国の申告書です。中国で124、旧ソビエトで34、全体の197のほとんどがこの両国で占められています。このデータはダイレクトに突然変異を用いて品種に登録された数であります、さらに、突然変異系統の間接利用についても別のデータベースに確かなとと思います。

座長：日本から寄与できること、海外から学ぶという所を、少し議論できたらと思います。昔は、海外協力で日本は教える立場でしたが、今はあくまで対等の共同研究という形で進められている時代です。そういう中で冷静に学ぶべき所があるかと思います。例えば、これまでお話をいただいた国や国際研究機関はいわば遺伝資源大国で、育種には突然変異はあまり利用されてこなかったという実態はあるかと思います。一方で、突然変異育種には基幹品種の遺伝子型を崩さない等の利点があり、突然育種を海外にもう少し普及させるということは充機能考えられるわけです。育種ではなく、生理分野で外国とのギブスドライクのポイントがありましたらお願いします。

有原：我々の場合にはギブスドライクはあまり考えておりませんでした。ただ、ICRISATでは、日本は土壌肥料研究が盛んなので、インド各地の試験で確認されていたイキマメとヒヨコマメはリン酸の施肥反応がない理由を解明してくれると期待していた部分はあったと思います。解明の鍵になったのはリン酸の評価法が日本と外国で違うということでした。ともすると日本人は控えめで自分を出すことをしないのですが、日本の持っている特徴を押していくことが非常に重要である場面があると思います。日本の持っている研究の水準や蓄積は、特に稲に関してはすごいものがあるということを自覚しなければならないし、
そのことが結局相互の利益につながっていくのだろうと思います。
座長：ありがとうございました。海外の経験者が多い中で今までの意見は皆さんがそれなりに感じていて、おそらく、なかなか難しいことであったと思います。良い話をしていただきました。海外とのギブアンドテイクでもって作物研究においてどのようにやっているのか、研究の内容も含めて会場の方からご意見がなければ終わりにしたいと思います。特に結論は出しませんでしたが、作物研究の海外の動向の共通のところに遺伝資源研究や突然変異研究があることを認識したことで総合討論を終わりにしたいと思います。
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