New rice varieties adapted to climate change in the Mekong River Delta of Vietnam

Chi Buu Bui[1*], Thi Lang Nguyen[2]

[1]*Institute of Agricultural Sciences for Southern Vietnam (IAS), Vietnam*
[2]*Cuu Long Delta Rice Research Institute (CLRRI), Vietnam*

Received 1 August 2016; accepted 21 October 2016

Abstract:

Although Vietnam is the second largest rice exporter in the world, the country has only recently met the demand for sustainable food supply at a national level, and not yet at a household one. In the early 1970s, the average rice yield in the Mekong River Delta (MRD) was 1.9 tons/ha and the annual production weighed 4 million tons. The current rice productivity and production has gained over 6 tons/ha and 24 million tons/year, respectively. This is a substantial increase. This progress in the MRD is in brief, due mostly to (1) Government policy, (2) Water management, and (3) Technological innovation and application with an emphasis on varietal improvement. As an impact of the ongoing El Nino Southern Oscillation (ENSO) phenomenon, severe droughts and salinity intrusion has been occurring in Vietnam's MRD and has caused varying degrees of damage to agriculture, fisheries and the livelihoods of people in the region. New rice genotypes have been released via both conventional breeding and marker-assisted selection. The introgression of target genes from wild species viz. *Oryza officinalis*, *O. australiensis, O. rufipogon* into cultivars has been conducted successfully. Commercial rice varieties, which are currently growing in the MRD for export, are listed as Jasmine 85, OM3536, OM4900, IR64, OM6162, ST3, ST5...

Keywords: ***climate change, El Nino, gene introgression, marker-assisted selection, wild rice.***

Classification number: ***3.1***

Introduction

The two primary rice bowls of Vietnam are the MRD, accounting for 54% of Vietnamese rice production, and the Red River Delta (RRD) contributing 17%. Both delta regions are comprised of large areas of fertile low laying land which is highly suitable for rice production. Both are blessed with abundant water from rain and from two of the largest rivers in the country. Affected by the monsoonal climate, rain, and the flows of those two rivers, the region experiences strong seasonal variations, suffering through floods in the rainy season, and water scarcity and salinity intrusion in the dry season. In addition, about half of the MRD is covered with acid sulphate soil. Water resource management helps alleviate the above production constraints and contributes to very high productivity in the delta regions, with rice crop intensity > 2 and yields of more than 5.4 tons/ha/crop over the delta regions.

Although Vietnam is the second largest rice exporter, it has only recently met the demand for food security at the national level, however, not yet at the household level. Many Vietnamese people do not have access to sufficient food. People who have an insufficient food supply account for 6.7% of the overall Vietnamese population, and 8.7% in rural areas. Approximately one million people in mountainous regions use maize and cassava instead of rice because of their severely restricted access to food sources due to low incomes and poor infrastructure in rural areas [1].

In Vietnam's sustainable development strategy, food security is always a top priority, seen as an ends to gain livelihood, political and social stability. After the financial crisis of 2009, one could observe a noticeable growth in the appreciation of the essential role of agriculture by the global society. Vietnam has recently been identified as an outstanding example of a country that has sucessfully overcome economic crisis from food security issues arrising from agriculture challenges.

Intensive cultivation of rice in the Mekong Delta has led to an increased threat of brown plant hopper populations and continuously adapting agriculture virus strains (e.g. blast), which transmit ragged stunt and yellowing diseases that further risk food security in the region.

Vietnam needs to deal with its decline in agricultural land for rice as well as future climate shocks including sea-level rise. Based on *status quo*, by 2030, projected decline in yields of rice in Vietnam in North Delta could be -2.2% and in South Delta could be -5.6%. This trend continues till 2050 where an overall Vietnam could experience yield loss by 20%. Subsequently, yield loss could be 32.6% in North Delta and 7.8 to 8.6% in

*Corresponding author: Email: buu.bc@iasvn.org

South Delta. By 2080, the picture continues to be negative. Predictions suggest that North Delta may experience loss of 16.5% annually. However, yield changes may vary between the seasons: -17.5% (summer/autumn), +11% (autumn/winter) in the South Delta; -23.5% (summer/autumn), +17.2% (autumn/winter) in the Ca Mau region of the South Delta, Vietnam [2].

Climate changes caused by El Nino have created severe drought and salinity intrusion into the MRD. On March 15, 2016, the Vietnamese government and the United Nations Development Program (UNDP) organized a meeting with donors, international organizations, and other partners to discuss joint efforts for drought response and recovery in the region.

In response to this urgent call, the CGIAR (Consulatative Group of International Agriculture Research) Centers operating in Vietnam, in collaboration with MARD (Ministry of Agriculture and Rural Development), organized a joint field assessment in the MRD to first-hand observe and assess the effects of the drought and salinity intrusion currently experienced by the region.

The CGIAR will contribute to solving the food security issue by studying global data and analyses from Vietnamese scenarios, and calculate forecasts, outline plans, and recommend CSR (Climate Smart Agriculture) options for integration into current and future donor-development intervention programs. These findings and plans can also be used to identify opportunities for research and development of programs that ensure future food security preparedness.

The current challenges for Vietnamese agriculture could be identified as follows: climate change due to extremely harmful weather, reduced arable land, water shortage, food and energy crisis, and population blooming.

Vietnam must deal with rising sea water levels to 15-90 cm by 2070, and a rapidly (21% rate) increasing level of rain fall by the end of century 21 as compared to the period of 1980-1999.

Varietal improvement for exporting and climate change

In the past, Vietnam had suffered a series of long and terrible wars during which rice productivity could not meet demand. In the case of the MRD, during those wartimes rice fields yield less than 2.0 tons/ha due to deepwater rice at 1.7 million ha including 0.5 million ha of floating rice which had a low yield. Rice production in 1975 was calculated at 4.0 million tons/year, but steadily rose to current yield records of 21 million tons in 2010. This change is substantial. Vietnam imported rice and wheat during those war time at roughly 2 million tons/year until 1989.

Recent agricultural progress in Vietnam is mostly due to (1) Government policy, (2) Water management, and (3) Technological innovation and application with an emphasis on varietal improvement. Vietnam has become a rice exporter (Table 1).

Table 1. Global rice market situation and Vietnam role (million tons/year).

Country	2009	2010	2011	2012*
India	2.15	2.23	4.64	8.00
Vietnam	5.95	6.73	7.00	7.00
Thailand	8.57	9.05	10.65	6.50
Pakistan	3.19	4.00	3.41	3.75
USA	3.02	3.87	3.21	3.45
Others	6.52	5.67	7.24	6.75
Global	**29.40**	**31.55**	**36.15**	**35.45**

*Estimated.

The most recent objectives of rice breeding has been to develop new varieties of rice suitable to match food security levels and maximize rice cultivator profit.

From 1991 until 2000, focus was on water management strategies to promote irrigation to rice fields, augment rice production, prevent salt intrusion, and improve sulfate toxicity in the Plain of Reeds (Dong Thap Muoi) of MRD. Rice growing areas yield as much as 5.7 million ha in 1986 rising to 7.66 million ha in 2000. That means that 2 million ha were augmented over 15 years (34%).

Rice breeding is now considered to be the most important focus in order to raise crop yield productivity. Throughout human history, food crises have often been solved by new inventions; these so called green revolutions have helped peoples deal with hunger. Due to IRRI Cooperation's rice improvement programs in Vietnam which installed IRRI elite lines throughout various regions, prebreeding derivatives have been introduced that allowed for rice crop cross breeding, which enriches the gene pool of wild rice species (*O. officinalis*, *O. australiensis*, *O. rufipogon*).

The new rice breed IR8 is called Than Nong 8 and Nong Nghiep 8 in South and North Vietnam respectively. The breed provides a much higher yield compared to other leading local breeds. Subsequently, new varieties had been engineered and released as Than Nong 73-2, IR36, IR42, IR19660, IR48, IR4570, IR8423, IR64 in the South. However, due to Vietnam's history with war, the country's yield potential has not been fully utilized partially due to the lack of intensification. Since 1975, new technologies have not been fully adopted due to the lack of appropriate agriculture policies, which are needed to motivate rice farmers to use those new technologies. The lack of adequate policies is one of the key reasons why Vietnam imported rice during the period of 1962 until 1987, during which times includes a period of four continuous years that Vietnam had to import over one million tons/year from international sources. In 1967, 1.25 million ton was imported; in 1968, 1.23 million tons was imported; in 1969, 1.03 million tons was imported and in 1970 rice imports peaked at 1.26 million tons imported.

Vietnam became a rice exporter in 1989, two years after the new policies from Doi Moi were implemented. At that time, the leading rice varieties were IR64, IR17494, IR50404, VND95-20, OM1490, OM576. These new varieties have helped average grain yield continuously increase at 0.11 tons/ha/year in the most recent 20 years.

These changes are due to breeding and seed programs, and certified rice seeds have been used from 2% up to 28-30% during the 10 most recent years in the MRD [3]. With a 10% grain yield resulting from the use of certified seeds, a gain of at least 500 thousand tons is estimated annually. This success becomes a prerequisite to develop the new program "One Must, Five Reductions" by MARD used to support sustainable rice production in the MRD (the program requires the use of certified seeds, a reduced seeding rate, N fertilizer application, pesticides, postharvest loss, and water consumption).

In the beginning, rice farmers had a very negative opinion of certified seeds; 53% of the farmers understood less than 40% about certified seeds. However, after participating in community-based farmer group demonstrations, trainings and field visits, 87% of the farmers understood 70% about certified seeds [4]. Nearly half of the farmers had low opinions about the seeds (47%), and approximately 1/3 of them had high a high opinion of the seeds (40%) with three reductions and three gains before participation in community-based farmer groups showing the benefits of certified seeds, training farmers on seed use, and observing field demonstrations. However, after the demonstrations, more than 80% of them agreed to accept the new varieties of rice seeds that offer short duration genotypes resistant to brown plant hopper, blast and a higher export quality (Table 2).

rice varieties grown in the MRD for export are Jasmine 85, OM3536, OM4900, IR64, OMCS2000, OM6162 (drought tolerance), ST3, ST5, VND95-20.

Promising rice varieties: Recently released by MARD are rice varieties incorporating HYV (High Yielding Variety) and good grain quality properties as OM5756, AG1 (OM6377), HG2 (OM6161), OM6162, OM6677, OM6976, OM7347 (aroma and drought tolerance). Most of these rices have a long slender grain shape and are good export quality.

MAS (Marker-Assisted Selection) for grain quality properties

AC (Amylose Content): AC is one of the important properties of grain quality. A polymorphic microsatellite sequence closely linked to the *Wx* gene has been reported. Analysis of chromosome 6 with 20 SSRs, markers RG42 and Waxy were used to select the promising lines.

Table 2. Farmers' perceptions of certified seeds and three reductions and three gains (% farmers) (n = 230).

Level of perception	Participation in community-based farmer groups, training and visiting field demonstration		χ^2
	Before	*After*	
Certified seeds			
Low	53	4	11,224**
Medium	10	9	
High	37	87	
Total	**100**	**100**	
Three reductions three gains			
Low	47	1	12,865**
Medium	13	1	
High	40	98	
Total	**100**	**100**	

**Significant at 1%.

Level of perception: Low: ≤ 40% right answers toward perception on technology; medium: > 40-70% right answers toward perception on technology; high: > 70% right answers toward perception on technology.

New rice varieties adapted to farmers' demand under climate change

Commercial rice varieties: Currently, Three new varieties with low AC such as: OM4900, Hau Giang 2, OM7347 were released due to MAS [5].

Aroma: The genomic clone RG28, which is tighly linked to the *frg* gene in rice, provides a performance MAS in the rice breeding program. This study was conducted to identify the target gene by using SSR (RM223) and STS designed from RG28 on Chromosome 8 (RG28FL-RB) linked to *fgr* gene in rice to obtaine salt tolerance genotype plus aroma such as OM4900 (3 dS/m at seedling stage).

Major biotic and abiotic stresses under climate change

To sustain current yield levels, rice improvement has been focused on releasing new genotypes with stable tolerance at the target stresses under climate change. Brown plant hopper blooms up beside blast and bacterial leaf blight damge.

The favorable soil for rice cultures in the two largest granaries in Vietnam is alluvial soil at 1.18 million ha (30.1%) in MRD. The unfavorable areas with various soil types is presented in Table 3.

Table 3. Problem soils in rice culture areas in MRD.

Soil type	MRD (%)
Acid sulfate	40.8
Salinity	18.9
Peat soils	20.0
Grey soils	3.4

In acid sulfate soils, low pH, aluminum toxicity, iron toxicity, and low phosphorous are considered as the primary limiting factors for rice growth. Currently, water management and agronomic practices have been recommended. Some improved genotypes have been identified to tolerate drought, salinity, and acid sulfate, but it is not stable due to climate change and unfavorable weather patterns.

For biotic stresses, brown plant hopper is often considered as rice production's most harmful pest. Due to increases in population and changing biotypes, current rice genotypes are not able to resist this pest for long periods. Introgression of target genes from wild rice species into cultivars is being implemented.

Blast disease is another important biotic stress. Many isolates have been collected throughout Vietnam, and gene *Pi-2* is considered to control most virulent strains in Vietnam beside other genes.

Bacterial leaf blight is the most significant problem in Northern Vietnam during the two main seasons, and in southern Vietnam during the monsoon season. Genotypes with *xa-5, xa-13, Xa-*

7, Xa-4, Xa-21 can control the virulent bacteria in Vietnam [3, 6].

Varietal improvement has provided farmers with the best materials available from pure line selection, introduction, and local hybridization.

Approximately 5,000 types of local rice and hundreds of populations of four wild rice species: *O. rufipogon*, *O. nivara*, *O. officinalis*, *O. granulata* have been collected, catalogued and evaluated. The resulting materials have provided donors for biotic and abiotic stresses [7]. Rice germplasm evaluation assisted by DNA markers has been conducted at some institutions in Vietnam to supply reliable information to rice breeders to assist with selecting appropriate materials.

The use of a gene pool from wild rice species fully intoduces a true introgression of desirable traits into HYVs such as AS996 (IR64/*Oryza rufipogon*), the first derivative which is tolerant to some major biotic and abiotic stresses, short duration, high yield, and wide adaptability, in particular Dong Thap Muoi acid sulfate soil area.

Focus from biotechnology applications of rice have been on: (1) The functional genomics to improve the traits in which the conventional breeding is not available, (2) MAS in rice breeding, and (3) Genetic diversity assessment. Rice biotechnology has significant potential to help the field of agriculture to contribute to the goal of country-wide sustainable development, which is to adapt to climate change with an emphasis on salinity, submergence, and drought and heat tolerance; to increase the nutritional and market values of food; and to enhance the stability and sustainability of the agro-ecosystem.

Several wild species with strong degrees of resistance to pests have been identified. *O. rufipogon* is a wild rice breed strongly tolerant to acid sulfate soil which occurs in Dong Thap Muoi, Vietnam, and has been identified to have an appropriate population for QTL mapping of aluminum toxicity with its derivative as the AS996 genotype [8].

The use of MAS will increase the efficiency of selecting a rice breeds most desirable traits. Supported by the Rockefeller Foundation (RF), one can identify necessary facilities for this PCR-based markers' application. Teams use RAPD, AFLP, SSR, STS to detect target genes that control the resistance of major biotic and abiotic stresses. Drought, salinity, and acid sulfate are the key challenges beside major biotic stresses in a rice breeding program used for food security.

Drought tolerance was assessed by both phenotyping and genotyping (RM201 on Chromosome 9) to develop OM7759, OM7930 and OM7935. Genotype OM6162 is growing in large scale areas. However, the stress of drought is still the biggest challenge, in particular at flowering stage.

Salinity tolerance was conducted under field conditions and MAS (Chromosome 1 and 8). The promising rice lines at seedling stage with survival days of 15-20 days, were noticed as: EC = 7 dS/m: OM5629, OM8108; EC = 5 dS/m: OM6600, OM8104 (+ drought tol), OM6328; EC = 4 dS/m: OM6677, OM6377, OM2395 and MNR4; EC = 3 dS/m: OM4900, OM6162 (+ drought tol); and the rice genotype did not express its salt stress in reproductive stages yet.

Heat tolerant rice genotypes can be recognized through multilocational yield testing and MAS (Chromosome 3 and 4) as followed: OM8108, HTL1, HTL2, HTL3 and HTL4. Heat shock protein HSP90 was notice to express in rice plant via Western blotting under temperature of over 36^{o}C daily and 27^{o}C nightly, in Ninh Thuan province.

Phosphorus-deficient soils is another major yield-limiting factor in the Mekong Delta, especially in acid sulfate soils. A major QTL for P uptake had been mapped on Chromosome 12 (RIL6 population of AS996/OM2395). OM4498 and AS996 were selected and developed successfully in MRD.

Sub1, a major QTL on Chromosome 9, provides protection for 10-18 days of complete submurgence. IR64 Sub1 has been exploited in rice breeding in MRD to obtain submergence tolerance rice varitey OM1490 - *Sub1*.

Looking to the future

Looking to the future, one must (1) Broaden the genetic background of rice varieties from both landraces and wild rice species; (2) Break the yield ceiling and stabilize productivity; (3) Improve grain quality and nutrition value of rice; and (4) Meet the demand of climate changing and water deficit to have drought tolerant genotypes and others tolerant to abiotic stress.

REFERENCES

[1] Nguyen Van Bo, Bui Chi Buu (2010), "Rice Production in Vietnam: Achievements, Opportunities and Challenges", *Vietnam Fifty Years of Rice Research and Development*, Agric Publisher, pp.19-36.

[2] P. Teng, Mely Caballero-Anthony, Jonatan Anderias Lassa (2016), "The Future of Rice Security Under Climate Change", *NTS Report*, **4** (S. Rajaratnam School of International Studies).

[3] Bui Chi Buu (2009), "Rice Production in Vietnam", *in Proc. of The First Vietnam Rice Festival in Hau Giang,* VNA Publishing House, pp.17-32.

[4] Truong Thi Ngoc Chi, Tran Quang Tuyen, Tran Thi Ngoc Mai, Nguyen Van Khang, Le Van Tinh, Le Thi Ngoc Anh (2011), "Effect of Community-Based Farmer Groups with Same Preference on Adoption of Technology", *OmonRice*, **18**, pp.157-166.

[5] Nguyen Thi Lang, Bui Chi Buu, Nguyen Van Viet, A.M. Ismail (2010), "Strategies for Improving and Stabilizing Rice Productivity in The Coastal Zones of The Mekong Delta, Vietnam", *Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land and Water Interface*, pp.209-222.

[6] Bui Chi Buu, Nguyen Thi Lang (1998), "Rice Germplasm Evaluation Assisted by DNA Marker for Bacterial Leaf Blight", *Agricultural Biotechnology: Laboratory, Field, and Market*, CISRO, Darwin, Australia, pp.69-70.

[7] Bui Chi Buu, D.W. Puckridge (2001), "Impact of Agricultural Research and Training on The Productivity and Farming Systems in The Mekong Delta", *The Impact of Agricultural Research for Development in Southeast Asia*, Proc. of an Int. Conf. Held at The Cambodian Agric. Res. and Develp. Inst., Phnom Penh, Cambodia, pp.123-135.

[8] Bay D. Nguyen, D.S. Brar, B.C. Buu, N.V. Tao, P.N. Luong, H.T. Nguyen (2003), "Identification and Mapping of The QTL for Aluminum Tolerance Introgressed from The New Source, *O. rufipogon* Griff., Into Indica Rice (Oryza sativaL.)", *Theor. Appl. Genet.*, **106(4)**, pp.583-593.