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A rational look at genetic improvement of rice in Sri Lanka

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Abstract

Recorded history of rice cultivation in the country begins with the inception of Journal "Tropical Agriculturist" by the Ceylon Agricultural Society in early 20th Century. Accordingly, the maximum number of rice varieties known with names in 1902 were only three hundred. This number appeared gradually declining as the maintenance was farmer dependent. The varieties too were impure, heterogeneous land-races. Genetic improvement of rice begins with the production of improved seed of variety 'Hathiyal' by Dr. Lock in 1914. Pure-line or pedigree selection was commenced from 1920s to purify and improve traditional varieties and the best adaptable 21 pure-lines were identified by 1940s. Nevertheless, the rice productivity was inadequate to feed the local population and crossbreeding was resorted subsequently to improve yields. The crossbreeding was known well ahead of the establishment of DNA structure and was confined to the rice genome with no genetic modifications involving alien genes. The first set of crossbred varieties, identified as old improved varieties (OIVs), brought together the desirable traits from different cultivars but the defects inherent in traditional plant type did continue. Conceptualizing a photo-synthetically efficient, lodging resistant and fertilizer responsive new plant type in 1960s by the International Rice Research Institute (IRRI) paved the way to develop modern, new improved varieties (NIVs). Stress tolerance, biotic and abiotic, was also incorporated in the process of crossbreeding. The improved yield potential of modern short duration varieties made them cultivated predominantly making the country almost self-sufficient. Grain quality was given prominence subsequently after reaching the self-sufficiency level. However, the biodiversity of rice was sacrificed inadvertently with the advancement of genetic improvement. The future genetic improvement will have to continue with stress tolerance breeding as long as the process of evolution continues. Also, innovative breeding techniques such as mutation breeding may be employed to improve potential of traditional quality rices. In addition, exploitation of uni-culm advantage and hybrid vigor is needed to

improve yield potential further. Application of biotechnological and molecular biological tools may help to expedite the process of crossbreeding with improved precision. Let genetic modification research be with International Institutes.

Keywords: Crossbreeding, Glycemic index, Grain quality, Land-races, Stress tolerance

Introduction

This topic needs a fair discussion as some critical statements made by interested groups, distorting the facts on genetic constitution of modern rice varieties, have caused serious repercussions in the society. The genetic improvement process of rice for more than a century in the past is, therefore, summarized critically in this disclosure to give an unbiased insight to the procedures involved.

Rice cultivation in Sri Lanka is speculated to be prosperous in the past, especially during the era of King Parakramabahu the Great, but we have no records of rice productivity, varieties and technologies adopted leading to an exportable surplus in the country. If any one is equipped with the above facts, let the Department of Agriculture test them for immediate recommendation. The Department of Agriculture is mandated to generate, test, recommend and extend the agricultural technologies for the farmer.

The Ceylon Agricultural Society kept records of the past information on rice cultivation in the Journal of Tropical Agriculturist. This paper is primarily based on the facts provided in the journal, but not on legendary tales and gossips inherent down the generation. The journal "Tropical Agriculturist" began much before the inception of the Department of Agriculture in Sri Lanka.

Records of indigenous land-races in Ceylon

Molegoda (1924b) reported a display of 300 named traditional varieties in 1902 by Nugawela Disawa in the Agri-Horticultural and Industrial Exhibition held in Kandy. This is the oldest recorded information of traditional rice varieties in Sri Lanka. Few years later, Molegoda was in possession of this collection but with few numbers missing. However, he was unable to complete the whole set as the missing ones were not cultivated further. Subsequently, he was able to list the names of only 168 varieties of paddies grown in the years 1915 and 1916. This number was further reduced to around 150 when a collection was made for British Empire Exhibition, probably held in early1920s; the naming and maintenance of traditional varieties were farmer dependent and not properly organized. Molegoda ultimately listed 567 known names of varieties, including those introduced from other countries, cautioning the reader about possible duplicity/ multiplicity of names and varieties. In addition, he observed considerable heterogeneity within and among the so called varieties. They were more of land-races with inherent heterogeneity and were used in subsequent genetic improvement by selection.

Furthermore, de Soyza (1944) published a list of 42 hill paddy (upland/chena) varieties. These varieties were apparently not given prominence in genetic improvement.

Inconsistencies in maintenance, naming; duplication (both varieties/names) and heterogeneity within varieties (land-races) were noticed. The total number of names recorded was around 620, inclusive of introductions during this period.

Genetic improvement by selection

Dr. Lock appeared to be the first person who attempted purifying popular land races by producing improved seed paddy since the Department of Agriculture was established in 1912. Dr. Lock's improved seed of Hathial, a seven month rice variety, appears frequently in the past literature. The procedure followed in varietal purification could be seed selection (Molegoda, 1924a), a procedure similar to mass selection without progeny testing. However, four kinds of selection procedures (casual, mass, pedigree/ pure-line and continuous) were employed in the purification of land races (Lord, 1927).

The Division of Economic Botany of the Department of Agriculture (Summers, Iliffe, Lord, Haigh etc.) initiated and continued the pure-line (pedigree) selection program from early 1920s to purify and improve productivity of traditional varieties/land-races. In the process of selection, regional adaptability of the selections interfered with the progress and had to identify 19 different Regional Paddy Seed Stations for selection, testing, demonstration, production and distribution of the seed material (Lord, 1927). Pure-line selection was continued by the paddy officer, Wickramasekera and others till 1940s and 21 pure-lines (Table 1) were identified for purity maintenance and multiplication in four regional paddy seed stations (Rhind, 1948). Further multiplication was done thereafter in government farms and distributed for cultivation.

Gunawardena and Wickramasekera (1947) published botanical characteristics of the final list of pure-lines. Accordingly, only two pure-lines, Kurluthuduwi b 13 and Podiwi a8, were white pericarped. Both these varieties were photosensitive and confined only to Maha season cultivation. All the others were red pericarped.

The medium aged (4 – 4.5 month) varieties occupied the major extent of the annually cultivated rice lands.

Rice is an obligate in-breeder; any plant isolated from an inbred population breed true to type. Heterogeneity within land-races disappeared with the drastic reduction of the number of varieties (620 to 21) from the field and resulted in genetic erosion leading to decline of biodiversity. Adaptability to different agro-ecological environments was realized important, before recommendation for cultivation. The major group of cultivars were in medium (4 - 4.5 months) age category. Legitimacy of cultivars (e.g. Kuruluthuduwi) at present needed to be verified. Pest incidences (paddy fly, stem borer, swarming caterpillar) were reported with traditional cultivars.

Table 1. Purity maintenance list of pure-line paddies, adopted from amended Departmental Circular No. 156 (1948) – Trop. Agric. CIV (2): 97-98

5 – 6 month varieties (long duration)	
Podiwi A3* **	Molagusamba 1 18 6
Kohumawi B 11	Kurulutuduwi b 13*
4 – 4 ½ month varieties (medium duration)	
Deweredderi 26031**	Vellai Illankalayan 28061
Balamawi 31009	Perillanel 26014
Oddavalan 2449/20	Honderawala 868
3 – 3 ½ month varieties (short duration)	
Madael 38 MY 137	Suduheenati 1 CPYN 19**
Suduheenati Hf 9	Sinnanayan 38 Y 2203**
Sulai 27614	Pachchaiperumal 2452/11**
Kaluheenati 39 YM 3254	Rathkarayal 38 YM 3753
Dahanala 37 YM 2014	Murunga 39 YM 137
Vellaiperumal 28724	

**white pericarped*
*** Podiwi a-8, Dewareddiri 26081, Sinnanayan 38 YM 2208, Pachchaiperumal 2462/11, Suduheenati 1 Cpy-19 in Botanical Descriptors by Gunawardena and Wickramasekera, (1947) Trop. Agric. CIII (2):105-112*

The impact of pure-line selection was insignificant and inadequate to meet the rice requirement locally (Table 2). This was the turning point to pursue crossbreeding.

Table 2. Annual rice production data in 1940s (Adopted from Trop. Agric. 1951, CVII (1):30.)

Period	Extent (ha)	Production (t)	Productivity (t ha^{-1})
1944	417097.97	278107.20	0.66
1945	362591.09	221409.63	0.61
1946	375335.22	232685.63	0.61
1947	375175.30	236166.76	0.62
1948 (*Yala*)*	138888.66	89063.52	0.64
1949	434333.19	312322.56	0.71
1950**	437901.21	307508.81	0.70

** Data from one season (minor season) **Estimated figures*

Crossbreeding – Old Improved Varieties (OIV)

The concept of crossbreeding in rice emerged as early as in the year 1927 in Sri Lanka, but not being pursued as variability of traditional types/land-races was not fully exhausted by pure-line selection (Lord, 1927). Despite the efforts made in pure-line selection; 1. the Ceylon government imported two-third of the rice requirement of the country in 1940s (Anonymous, 1945) and 2. the national average yield was very low and around 13 bushels per acre (0.65t ha^{-1}) (Table 2). These were the deciding factors leading to crossbreeding in the genetic improvement of rice. Accordingly, Prof. M. F. Chandraratne, Botanist and the Senior Agricultural Research Officer, Department of Agriculture, initiated the crossbreeding program in 1950 at the Dry Zone Agricultural Research Station, Mahailluppallama, but transferred to Central Rice Breeding Station, Batalagoda in 1952 due to unavailability of assured water supply for bi-seasonal rice cultivation (Senadhira *et al*., 1980).

Crossbreeding was based on Mendelian and quantitative genetics principles and confined within the rice genome. DNA structure, Central Dogma of molecular genetics were not established during this period. The main objective of crossbreeding was to bring together the desirable traits determining yield, pests and disease resistance, fertilizer response etc. scattered in different varieties to improve productivity. However, the progress was limited by incompatibility and poor combining ability experienced among the traditional varieties.

Rice varieties of different age groups, namely H4, H8, H105, H501 (4 – 4.5 month), H7 (3.5 month), H10, 62-355 (3 month), H9 (5 - 6 month) were released under this program. H4 occupied above 60 per cent of the cultivated extent in *Maha* season within few years after release. Medium age (4 – 4.5 month) varieties continued dominating the annual cultivated extent of rice. However, this program was discontinued abruptly with the conceptualization of new plant type for rice by the International Rice Research Institute (IRRI) to develop new improved varieties (NIV) with enhanced physiological efficiency.

DNA structure (Watson-Crick Model, 1953) and Central Dogma of molecular genetics were not established when crossbreeding initiated in Sri Lanka and the term 'Genetic Modification (transformation or engineering)' was not known to the rice breeders. Biodiversity was further reduced by confining to eight OIVs developed using few parental varieties. Poor combining ability and incompatibility reactions among traditional varieties were exposed. Medium aged (4 – 4.5 month) varieties continued to be the major age group of cultivars

Crossbreeding – New Improved Varieties (NIV)

There were inherent defects in the plant type of traditional and old improved varieties limiting productivity. Tall and leafy characteristic made them lodging susceptible and photo-synthetically inefficient with poor net-assimilation rate. The grain:straw ratio was low as partitioning of photosynthates favored vegetative growth. Added fertilizer too promoted vegetative growth making the plants lodge, sometimes prematurely, causing heavy losses.

The basic plant type structure for the lowland rice ecosystem was conceptualized by the International Rice Research Institute (IRRI) at its inception in early1960s, probably influenced by the Norman Borlaug's ideology in wheat green revolution. Accordingly, the plant architecture in new improved varieties (NIVs), especially the plant height and canopy structure, was changed to improve physiological efficiency (net-assimilation rate); partitioning photosynthates to promote grain:straw ratio; improve lodging resistance and fertilizer response.

The above changes in the plant-type were accomplished conventionally through crossbreeding within the genome of rice. Engkatek (Indonesian) and derivatives of Dee-Geo-Woo-Gen, a dwarf mutant (natural) isolated in Taiwan, were involved in the development of improved varieties. No genetic modifications or alien genes outside rice genome were used in this process. The NIVs replaced the existing cultivars within a short spell of time (Figure 1) and increased the average national productivity (Figure 2). The present average national productivity is 4.6 t ha^{-1} (92 bu/ac).

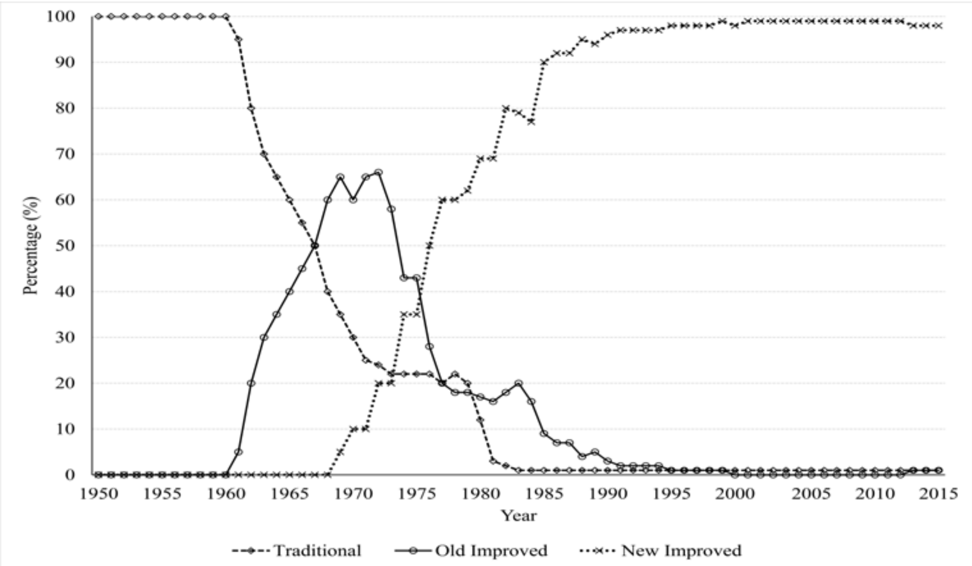

Figure 1.Percentage distribution of rice varietal categories in Sri Lanka, 1950 – 2009 (Source: RRDI, Batalagoda)

The short duration varieties (3 – 3.5 month) with the improved yield potential gained prominence in rice cultivation by reducing drought induced crop failures and making rain-fed cultivation and double cropping *(Yala, Maha)* beneficial. However, overlapping of rice crops increased significantly, particularly in irrigated lands, promoting pest and disease cycles to continue throughout the year.

Inadvertently, the diversity in cytoplasmic genome too was reduced by the use of dwarf parent as the female. The changes made in the plant type was misinformed to the general public by critics as genetic modification (GM).

Abiotic and biotic stress resistance

Abiotic and biotic stress tolerance was attended as and when they interfere with the crop productivity. The abiotic stress factors (iron toxicity, salinity, acidity, drought, flash floods, temperature extremes etc.) are mostly regional issues and were dealt within the biological limits of the rice plant. Presumably, there is room for further improvement of these traits as the genetic diversity of rice germplasm is not exhausted in these fields. However, the marginal rice lands identified with extreme abiotic stress conditions could not be converted into economical units by varietal resistance/tolerance alone.

Among the biotic factors, brown plant-hopper, gall midge, blast and bacterial blight were considered major pests and resistance to them was mandatory to release a variety. Unlike the abiotic factors, the causal agents of biotic stresses – insect pests and plant pathogens – are capable of having mutational changes to develop virulence and overcome host plant resistance. This may inevitably keep the plant breeders occupied in breeding for resistance.

However, the major reason for outbreak of pest incidences at presents is overlapping of crops due to lack of coordinated seasonal cultivation (specially in irrigation schemes) and increased cropping intensity, particularly as a result of yield improvement in short duration varieties; as a result, the pest cycles tend to continue year-round. The traditional varieties too succumb to most of the major pests and diseases in rice.

Grain quality

Allard (1960) defines quality as fitness for the purpose. Apart from human consumption as a major staple, rice is being used in confectioneries, manufacture of alcohol beverages (sake, beer), animal feed etc. However, some interested groups criticize the cooking and eating qualities of NIVs at present to promote obsolete traditional cultivars, without proven scientific evidence. The local rice breeders in the past were more concerned with quantity than with quality to assure food security in the country. That was the mandate of the Department of Agriculture; now the breeders can engage in the development of quality rices for consumer preference.

The cooking and eating quality of rice differs from one country to another and from person to person as well; parboiled or row milled, long slender or short round grain, aromatic or non-aromatic types, low, intermediate or high amylose content etc. Basmathi of Pakistan/India, Jasmine rice (Kao Dwakmalee) of Thailand are internationally popular, long grained traditional aromatic rices. The indigenous aromatic rices in Sri Lanka are not long grained. The only traditional quality rice retained in the local market, Sri Lanka, is Suduru samba. Similarly, IR 64 (IRRI) and Koshi hikari (Japan) are crossbred varieties considered of superior quality. Bg 360 would be the landmark crossbred variety of this category in Sri Lanka.

Glicemic Index (GI) was not considered a quality parameter in rice genetic improvement. It implies the rapidity of appearance of the ultimate digested product (glucose) in blood stream. Recently, GI of modern rices was criticized to promote traditional rices without conclusive experimental evidence. GI is a variable irrespective of the origin of a rice variety, traditional or crossbred. Promotion of whole-grain parboiled rice may help contain rapid digestibility of high GI rices, if needed, in patients of non-communicable diseases.

The other side of the coin is that if all the rice varieties are of low GI (hard to be digested and absorbed), the purpose of eating rice is in confusion; the human nutritionists should express their unbiased view by comparing all cereal foods, including wheat flour products, to justify elimination of high GI rices from consumption.

Future genetic improvement strategies

Apart from breeding for tolerance/resistance to biotic and abiotic stresses, there are three logical options to improve productivity in rice: 1. mutation breeding (improvement of traditional quality rices); 2. exploitation of uni-culm advantage in direct seeded rice, and 3. development of hybrid rice.

The quality parameters of rice need to be considered with careful assessment of yield potential to be sacrificed while giving prominence to food security. The total genetic background of a variety influences its grain quality and the crossbreeding process would eventually disturb the background genome as well as the quality parameters. Hence, the yield improvement in traditional quality rices should be attained only by mutation breeding (point mutations) while retaining the background genome almost unaltered. This may also help to exclude poor combining ability and incompatibility among varieties in cross breeding.

The concept of uni-culm advantage is linked with direct seeded paddy, specific to lowland ecosystem (both irrigated and rain-fed). Sri Lanka is the only country practicing direct seeding of sprouted seed in puddled soil for crop establishment. The new plant type, with few heavy panicles and strong culms, conceptualized in the International Rice Research Institute (IRRI) should be the ideal model (ideotype) for this purpose. The parachute technique of seedling broadcast will help the rice plant in weed control, if employed as an alternative to the broadcast sowing of sprouted seed.

Hybrid vigor (F1) would be the ultimate option available to improve yield potential in rice. Hybrid rice, conceptualized by Prof. Yuan Long Ping, China, is gaining prominence in China and Vietnam. The research on hybrid vigor, development of parental lines (CMS, maintainer, restorer) and studies on improvement of cross pollination potential in seed production (CMS and hybrid seeds) should be continued locally. The country should not depend on hybrid seeds developed elsewhere as the danger of introducing new pests and diseases is linked with the seed importation. However, hybrid rice technology may be too intensive for the local rice farmer and has to be field tested thoroughly for its appropriateness prior to recommendation.

The biotechnological tools may help to expedite and improve precision of future crossbreeding programs, but need research efforts to perfect them. Development of perfectly homozygous individuals by F1 anther culture (double haploids) and tagging respective genes for stress tolerance in marker aided selection are two options immediately available for this purpose. Research in these fields are already in progress at the Rice Research and the Development Institute.

Genetic transformation in rice is a long shot within the available quantum of qualified scientists and the research infra-structure in Sri Lanka. Studies on performance of alien gene/s in totally different genetic backgrounds should be left with the International

Institutes unless we are competent and equipped to perform such research without contradicting the government policies. We need to evaluate the outcome of such research projects critically for their appropriateness in local rice farming.

References

Allard, R. W., 1960, Principles of plant breeding, John Wiley & Sons, Inc., New York, pp 485.

Anonymous. 1945, A draft scheme for the development of the paddy industry in Ceylon. Tropical Agriculturist Vol. CL, No. 8:191-195

Gunawardena, K. J. and G. V. Wickramasekera. 1947. Botanical characters of paddy. Tropical Agriculturist Vol. CIII, No. 2:105-112.

Lord, L.,1927. The selection of pure-line strains of paddy, their testing and distribution. Tropical Agriculturist Vol. LXVIII, No. 5:309-318

Molegoda, W. 1924a. Selection of seed. Tropical Agriculturist Vol. LXII, No. 1:16-17

Molegoda. W. 1924b. Varieties of Ceylon paddy. Tropical Agriculturist Vol. LXII, No. 4:218-224

Rhind, D. 1948. Pure-line paddies; maintenance of purity. Amended Departmental Circular No. 156. Tropical Agriculturist Vol. CIV, No. 2:97-98

Senadhira, D., M.P. Dhanapala and C.A. Sandanayake. 1980. Progress of rice varietal improvement in the dry and intermediate zones of Sri Lanka. In rice symposium 80. Dept. of Agriculture, Sri Lanka. 15-32.

Soyza, D. J. de. 1944. Hill paddy cultivation in Ceylon. Tropical Agriculturist Vol. C, No. 4:211-218.