

Rice breeding in retrospect

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Crop science harmonizes genetic improvement with crop husbandry. Rice yields in the temperate regions were higher than in the tropics due to this synergism. The turning point for elevation of rice yields in the tropics was the genetic improvement based on plant type. The yield potential of tropical rice was nearly doubled with the development of semi-dwarf cultivars. These cultivars have successfully elevated the plane of crop husbandry, at least as reflected in the rate of fertilizer use. A national grid of genetic improvement was in place by the mid-1960s with the object of incorporating the plant type attributes into the locally grown and consumer-accepted cultivars. The elevation of yield potential, which was convincing from Taichung (Native)-1 to IR 8, and thereon to Jaya, seemed to have been stalled. The change in the plant type of cultivars had its impact on the status and severity of insect or disease pressures on the rice crop. Improved technology may contribute either to efficiency in production or to convenience in farming. The acid test for any technology is the reduction in cost of the produce. Development is compelled to be opportunistic, merely selecting among existing possibilities. Science, in contrast, is expected to be creative and to expand the realm of possibilities. Production breeding aimed at an elevation in yield potential was sidetracked due to competing priorities for consumer-preferred grain quality and for resistance to biotic and abiotic stresses. The national concern regarding rice in the 1950s was the expansion in production. This concern was changed in the 1970s to factor productivity for land, water and time. Contemporary concern is profitability of rice farming. This shift in priority from production to productivity, and then on to profitability is an index of progress with technology. It is also the continuing challenge for the future.

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‘WE live forward, but we can only think backward’, Kier Kegard said. The practice of rice breeding is dated back to remote antiquity. It progressed with the identification, evaluation and selection of variants (mutants) in a population, and determining their suitability to specific crop-growing conditions. This age-old method has gained scientific validity and stood the test of reproducibility with the discovery of Mendelian principles of heredity. Apropos this landmark, the progress of rice breeding has been rapid and can be recognized under fairly well-defined steps, viz. transfer of single (simple) traits, induction of mutations, transformation of the plant type, exploitation of hybrid vigour and application of biotechnology. Each one of these steps, in its prime, has flaunted for itself a ‘modern’ label and retrospectively the preceding step with a ‘classical’ or ‘conventional’ label. Such condescending label of methodologies, leads to bypassing the available opportunities. Prudence dictates the choice of expedient and cost-effective techniques in every given situation – overcoming the temptation of allurements to novelty.

Plant type-based breeding has retained the appeal and demonstrated the utility for a long period and for a good reason. Short stature, non-lodging habit and erect foliage (collectively called ‘good’ plant type) are indisputably related to photosynthetic efficiency and to a favourable partitioning of the biomass so produced into structural and economic components of the rice plant. This realization was no serendipity, but the result of intensive and prolonged research relating plant form to crop function. If this is a triumph of the Japanese plant physiology as a science, it is a triumph in equal measure of the technological thrust that it has generated and the institutional organization that it has ushered over the last half a century.

A mutant in the cultivar, Chu-wu-gin in Taiwan conformed to the positive attributes of good plant type envisioned by Japanese scientists. This semi-dwarf mutant was in an indica cultivar and this trait is also simply inherited. These factors favoured a rapid incorporation of this trait into different genetic backgrounds – a triumph of technology. It is also fortuitous that the International Rice Research Institute (IRRI) was established after the elucidation of the plant-type concept and the availability of semi-dwarf indica cultivars from Taiwan. IRRI had the

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vision to recognize and articulate the value of this germplasm for leveraging the tropical rice yields. It is a triumph of the institutional organization that an international network could soon be put in place – leading eventually to cultivars, with a range of variation in maturity, grain type and resistance to biotic and abiotic stresses. Hence these cultivars became popular in tropical Asia, Africa and Latin America.

To put in perspective, progress with the plant-type breeding has been rapid and impressive; whereas an earlier effort with a similar objective – employing the japonica–indica hybridization – has been protracted and failed to produce commensurate results. The difference lies in polygenic control of the japonica plant type, and the non-availability of an easy ‘marker’ for selection. In the contemporary scene, the transfer of genes for β -carotene synthesis from japonica (golden rice) to indica background will be a harder task, than for example, incorporating a single gene, which controls the plant type.

In plant-type breeding, the gene, which controls the plant type in itself, is not credited with the elevation of photosynthetic efficiency and/or partitioning the biomass – in popular parlance, the yield potential. Even a cultivar with a good constellation of genes can be impeded from manifesting its potential when its plant type is poor. Incorporation of semi-dwarf gene into such a cultivar releases the ‘block’ in realization of high yield. Not all semi-dwarf cultivars are high-yielding. Neither does every local cultivar produce high-yielding semi-dwarf derivatives. A case in point: between two semi-dwarfs of the same parentage, one cultivar (Jaya) has excelled the ‘miracle’ rice, IR 8 and ruled the seed trade for long; while the other (Padma) lost its patronage within a year of its release. The difference was in the intensity of selection and the resultant genetic constellation.

In plant-type breeding, the intensity of selection of plants can be increased in three ways:

- Expanding the F_2 population to five or six-digit level (easily achieved by the vegetative propagation F_1 plants) even from a few F_1 plants.
- Ensuring that the F_2 generation is predominantly semi-dwarf (by rejecting the tall segregants).
- Concentrating on vigour in F_2 stage, selecting only from, vigorous crosses and eliminating en block the less thrifty ones.

The F_2 generation is the most variable; and hence larger the F_2 population, greater is the prospect of selecting the promising segregants. For example, the coordinating centre of the All India Coordinated Rice Improvement Project (AICRIP) during the 1960s used to devote 20% of its experimental land for the F_2 generations of about 50 crosses.

In the early generation (F_2), visual observation is the only viable basis for selection. Since there exists threefold the

number of (undesirable) tall plants to the (desirable) semi-dwarfs; and the former smother the latter (and not in the reverse), visual selection in F_2 generation is most effective only when the tall plants are largely excluded from the F_2 population. It is possible to do so before transplantation of F_2 population, since the dwarf habit finds full expression by the three-leaf stage, particularly when the nursery is thinly sown. Pursuing all the three steps above, it has become possible to derive highly productive semi-dwarf cultivars such as Jaya, Sona, Phalgun, etc. in the early years of breeding, when the yield potential received single-minded attention. Many crosses involving Ratnagiri 64, Kolaba 540 and other early maturity cultivars have been summarily rejected as unpromising. This rigour in selection, and the emphasis on yield potential have been compromised in later years, distracted by the emphasis on grain quality and stress tolerance. The number of crosses has increased. The size of the F_2 population has reduced. The progenies in F_3 and later stages have expanded. Excitement over the progress in grain quality, stress tolerance, early maturity, etc. has slackened the attention to yield potential¹. A large number of cultivars have been released, but only a few are popular. The central and state releases number 86 and 726 respectively, by the year 2005, while the ongoing demand for breeders' seed of central releases is limited to 30 cultivars.

Emphasis on early selection (F_2 – F_3 generations) and vastly expanding the population size in early generations were the key practices that led to the identification of cultivar Jaya. After the lapse of a decade of success with this twin strategy, the scientific rationale underlying this practice has been critically examined by Yonezawa and Yamagata²⁻⁴. They observed the following key points:

- Genetic potentiality of crosses is determined essentially in F_2 and F_3 generations;
- Some morpho-physiological traits are predictive of yielding capacity of plants and lines;
- With a larger F_2 population, the selection among and within crosses is useful;
- Cross-combinations are therefore assessed by the presence or absence of the promising phenotypes, and
- F_2 population should be entirely discarded if no promising phenotype is found.

Skipping the procedure that led to enduring cultivars such as Jaya and ignoring the scientific rationale underlying the practice as ably demonstrated by Yonezawa and Yamagata²⁻⁴ are the reasons for en masse rejection of many cultivars released by the national and state research systems.

Neither the concept of plant type nor the products of breeding has met with an instant and easy acceptance. Mental blocks had to be surmounted at various levels. Unlearning was needed so as to modify the crop husbandry. Local cultivars were ear-weight type, while the new semi-dwarf cultivars were ear-number type. The former were

sensitive to crop density while the latter were not. Some major changes in crop husbandry were therefore needed. Without these changes, the observed impact on production would not have occurred.

The prototype of semi-dwarf cultivars, Taichung (Native) 1 has enthralled the farmers and scientists for its yield potential. In all other attributes – maturity, grain type and disease susceptibility, it has been a big disappointment. It therefore ended up as a concept (not a cultivar) and as a parent in hybridization with popular cultivars. The later versions, IR 8 and Jaya with progressive improvements in yield potential have gained a ready acceptance even when other deficiencies have not been fully eliminated. It must be evident that the yield potential is a universal value in plant breeding, and that it can overcome consumer resistance, at least partially and temporarily.

Dissatisfaction with the grain type of IR 8 and Jaya and impatience in developing the consumer-preferred semi-dwarf cultivars have resulted in the release of several ‘span’ cultivars which turned out to be either ephemeral or localized to small pockets. On the other hand, when the grain quality and/or stress resistance were an ‘add-on’ to the agronomic base (e.g. IR 8 or Jaya) and entailed no compromise in yield potential, the patronage, as exemplified in the cultivar Phalguna was speedy and enduring. It is thus unwise to ignore the yield potential, and get enthused by the progress on stress resistance and/or consumer-preferred attributes. Farmers will favour cultivars with a drag on yield potential only when the price incentives are attractive. Obviously, the yield potential is of universal value, whereas the value of resistance to stresses is conditional to the prevalence and severity of stresses. The value of aesthetic preferences associated with cultivars is conditional to the price differential with reference to the high-yielding standards.

The field experience with gall midge-resistant cultivars will bear out the above point. The early versions of gall midge-resistant tall cultivars (e.g. W 1263, etc.), which yielded around 3 tonnes/ha as against no yield at all with Taichung (Native) 1 and IR 8, could not dislodge the susceptible cultivar HR 35. When the gall midge-resistant semi-dwarf cultivar, Kakatiya, was available, HR 35 was quickly replaced even though it commanded a better price in the market. When a cultivar with a still higher yield potential and better grain quality such as Phalguna was released, it became popular both in gall midge endemic as well as non-endemic areas. Only when the new biotype of gall midge emerged in the population did the cultivar Phalguna lose its popularity. This insect pest was virtually eliminated from the regions which were long endemic to it. Had the programme been discontinued at the stage of W 1263 or Kakatiya, it is doubtful whether a total annihilation of the pest status would have ever occurred.

As an enterprise, rice farming has changed drastically over years. During the 1950s and 1960s, the concern was

the production per se, and the goal was to attain self-sufficiency. During the 1970s and 1980s, the concern was the factor productivity. The contemporary concern is overridingly the profitability, since the fixed costs have escalated, and the opportunity for alternate enterprises has expanded alongside the increased expectations from the farmers. The crux of the plant type concept is the improved efficiency, and this must be reflected in the yield potential of cultivars, which offer the technological route to check inflation.

A seed-to-seed maturity of 130 days (a summation of 25, 55, 20 and 30 days for nursery, tillering, panicle initiation and grain formation) is an ‘optimum’ of sorts for entrapping a high yield potential in a semi-dwarf rice cultivar. Farmed under irrigation and in sub-humid and semi-arid environments, cultivars of 130-day maturity have ushered the green revolution. Scarcity of water with resultant disputes, and opportunity for crop diversification will certainly bring down the rice area under these situations. However, there is no such opportunity for crop substitution (except the unattractive option of jute) in the rainfed lowlands of East India with different levels of submersion, and in the scattered waterlogged landscapes in South India. Under all these situations, there is a need for semi-dwarf cultivars that mature in 140–150 days. When the cultivar is of a poor plant type, late maturity is a liability. When the cultivar is of a good plant type, late maturity converts the vegetative lag’ into a productive phase. It is expected that late maturing semi-dwarf cultivars benefit from a greater contribution of pre-flowering photosynthates; and do not experience decline in leaf area prior to flowering. Both these factors contribute to high yield. It is regrettable that the national programme does not pay adequate attention to HYV cultivars in this maturity group.

Aromatic and slender-grained cultivars are numerous; but they are recognized to be low yielding and so are grown in only small pockets all over the country, patronized by the elite, and consumed on festive occasions. The wide popularity of basmati owed it initially to the choice in railway catering. The growing middle class population in India sustains the domestic demand and the international demand for basmati comes from the Middle East, Europe and USA, and partly from ethnic groups. Emphasis on the development of semi-dwarf basmati is justified, but paranoia is unfortunate; and disregarding the improvement of several other aromatic cultivars has been a serious mistake. Semi-dwarf versions of basmati have been available from the 1970s, accompanied by claims and disputations on grain and cooking characteristics. Pusa Basmati 1 is the first among the semi-dwarf cultivars that gained entry into commerce. Compromise on yield potential is acquiesced as inevitable. Serious doubts remain whether the intensity of selection for yield and quality have matched the challenge. Price-differential sustains the popularity of Pusa Basmati 1.

When IR 20, IR 22 and Tella Hamsa were released, there was a feeling that slender-grained cultivars were not expected to match the coarse-grained ones in yield potential, and so a handicap in yield potential was accepted in the assessment of cultivars. The goal was to achieve the replacement of local cultivars by the semi-dwarf ones. It was hoped that the first generation slender-grained cultivars would hasten this process. Further, farmers who raise the slender-grained cultivars will be no worse off than those who raise IR 8 and Jaya, since what is lost by way of yield is made good by higher price. It did not take long to combine the yield potential of Jaya with an excellent grain quality. The cultivar so produced, Sona, was even apprehended to be adulterated with basmati. There is no a priori reason to believe that dwarf basmati cannot match the yield level of Jaya. According a special status to basmati breeding, and by keeping it separate from the mainstream slender-grain programme, screening for quality got precedence over that for yield. Historically, the first semi-dwarf slender-grained cultivar produced in India was N.P. 130 mutant which was no match to the later introduced Taichung (Native) 1.

Basmati distinguishes itself among the slender-grain cultivars by an aggregation of several desirable characters; long and slender grain which elongates further on cooking, integrity of the cooked grain whereby the 'jacket' does not burst on prolonged cooking, good fluffy cooked product and finally aroma from grain-filling to post-cooking stages. Many slender-grained cultivars do possess one or more but not all of the basmati characters. Cross-breeding of chosen aromatic slender-grain cultivars can well result in derivatives similar to basmati, either as a result of recombination and/or transgressive segregation. In an attempt to breed high-yielding basmati cultivar, one is therefore not limited to use basmati as the parent for grain quality. To illustrate the possibility, it may be noted that long, slender-grain cultivar (Sona) was derived from parents with medium slender (GEB 24) and short bold, T(N)I1 grains. Further, an expansion of the genetic pool simultaneously expands the genetic base for selection and opportunity for even excelling basmati in some characteristics. An opportunity of this type has not been explored and exploited by the Indian programme. Over reliance on Basmati 370 as grain-quality donor and an apprehension that basmati qualities may get diluted when non-basmati parents are employed in hybridization, has fostered a conservative spirit which must be overcome in future work. The issue of a technical feasibility of combining the Jaya-level yield with basmati quality may be settled once and for all by fresh attempts of primary crosses (involving several basmati types with the best long-grained semi-dwarfs) and subjecting the progenies to the protocol adopted for the development of Jaya, Sona, Phalguni, etc. Selection must proceed in several steps: for plant type (the simplest) followed by the yield potential (dependent on parentage and selection pressure), leading to grain

type and finally aroma and cooking qualities. Should this effort fail in achieving basmati semi-dwarf with Jaya yield level, one should develop aromatic, semi-dwarf cultivars based on non-basmati aromatic parents. The technological challenge rests in bringing the quality products at affordable price, and in the innovation of new products, which conquer new markets. A stereotype that pervades the basmati improvement programme needs to be broken. A cultivar such as Jaya ought to be the yield standard in evaluating the semi-dwarf basmati cultivars. This is an opportune time to do so, since the trade is happy with the currently available semi-dwarf basmati cultivars.

Rice breeding has changed over years; from a hobby to an art, to technology, to a science, to a synthesis of scientific disciplines and finally to high technology. Advances in constituent scientific disciplines opened up new technological vistas, making it a veritable cornucopia. The generation of new technologies, their evaluation, the determination of niches in which the given technology performs best, and finally the conversion of the potentials of technology into economic gains remained the unchanging backbone of rice breeding. Irrespective of the means employed for the generation of a new genotype, the utility of the phenotype is best judged at the level of a crop – a community of plants. Since the technologies relating to cultivars are less expensive and more enduring than for example, the irrigation, chemicals and soil amendments, rice breeding is the bottom-line of rice development.

Given the broad spectrum of activities, functionaries of various hues (innovators, service functionaries, promoters) get marshalled into the rice breeding enterprise. A symphony of their action, a synthetic evaluation of men and materials, engendering professionalism, promoting team spirit and establishing the ground rules of credit-sharing are essential for the health and productivity of the rice-breeding enterprise. Innovative spirit ought not to be sacrificed at the altar of the service function. Networking of institutions should not be a functional replication of tasks, but a segmentation of an overall task so as to permit the cooperating institution to provide leadership and claim credit for a segment of the overall task, while continuing to play a service role on another segment.

It is natural for institutions and individuals to expect recognition for the contribution they make to the system. It is equally true that credit-sharing is the root cause of inter-personal and inter-institutional conflict. Rice breeding is a synthesis of scientific disciplines. A cultivar is more often the by-product of an inter-institutional testing or evaluation programme rather than a sole contribution of any one scientist. Any cooperative programme will endure only when each participant gains from the system as much as he gives to the system. The ICAR Coordinated Projects have been designed to meet this challenge. They are meant to develop dynamic programmes on an open-membership basis without compromising institutional loyalties; to provide a federal leverage for the state programmes and

to make the scientist a free cooperator, freed of the position in the hierarchy. These values that were evolved when the products of rice breeding were considered a public good, need to be readjusted in the context of private research and the Intellectual Properties Rights. A good starting point is to design the scientist's job description partly in innovation and partly in service function, so that he continues to grow professionally while serving the programme. A plant breeder whose work stops at the conduct of trials, and an entomologist whose work is limited to screening the donors and breeding material will soon be of a limited utility to the programme, and will also be de-professionalized among the respective peer groups. A professor can gain respect as long as he masters the horizons of knowledge. But a scientist can gain respect only when he transcends the known and workable. Articulation of a problem may be a good beginning, but is only the beginning and is far from the solution of the problem.

Rice breeding has moved hands from the economic botanists of the colonial era to the rice breeders in independent India, onto the multidisciplinary teams in the green revolution era and finally to biotechnologists. The objectives of breeding are largely determined by consumers; and the techniques employed are determined by the advances in allied sciences. The target of genetic manipulation has gradually shifted from the whole plant to the sub-cellular and molecular levels. Physiological functions (e.g. photosynthesis, reaction to pathogens, tolerance to insect pests) do not always remain in accord at different levels of organization – cell, tissue, organ, plant and crop. A phenotypic evaluation is therefore, to be necessarily done at the crop (community of plants) level irrespective of the means employed in the development of a new genotype. This is the *raison d'être* for crop science and for the interdisciplinary teamwork in rice breeding.

An assembly of an interdisciplinary team jeopardizes the team member's professional links with peers as much as it enables interaction among disciplines. Development of an improved genotype is only the seminal step in rice breeding. The evaluation of genotypes over different crop growing conditions cuts across institutional and political boundaries. Diverse functionaries – innovators, service functionaries, promoters – need to assess the genotypes before a germplasm line gets recognized as a cultivar, which is rightly the by-product of the testing programme rather than the exclusive contribution of a scientist.

A rice breeder needs to collaborate with a physiologist while engaged in production breeding, with the ento-

mologist and pathologist while engaged in genetic resistance to pests; and with soil scientists, physiologists and microbiologists while engaged in resistance to abiotic stresses. The effectiveness of the collaborating basic scientist is conditional to his being abreast with the state of knowledge in the respective field. It is therefore imperative that members of the interdisciplinary team continue to be engaged in basic research in their own field, while playing a service role as team members in the cooperative programme. Such an interaction will expand the horizons of perception and the areas of influence for every member in the team, rather than turning them into a generalist knowledge worker. A rice breeder who stays content with the conduct of yield trials, a pathologist or entomologist who stops at conducting the screening of germplasm and a physiologist/soil scientist who screens the germplasm and breeding lines for reaction to soil problems will soon get marginalized in the interdisciplinary team and lose their standing in his/her own discipline. A technologist is thus a scientist plus but not a para-scientist. He may enjoy no authority (like Project Coordinators) but can greatly influence the work of a multitude.

Institutions tend to be hierarchical, whereas successful networks operate on a level field. It is natural for institutions or individuals to expect recognition for the contribution they make. It is equally true that credit-sharing is the root cause of inter-personal and inter-institutional conflicts. But not all rewards and recognitions are monetary in nature; and they do not cease to be incentives to good work when the cooperators turn their attention to what they gain rather than what they give to the cooperative network and reflect upon the impact their contribution can make to the farming system.

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