The Scientific Implications of the High-Yielding Varieties Programme

RECENT TRENDS IN BREEDING RESEARCH IN ASIA

By

M.S. Swaminathan,
Indian Agricultural Research Institute,
New Delhi, INDIA.

....

INTRODUCTION:

Tropical or sub-tropical agriculture, characteristic of a large part of Asia, presents both special problems and unique opportunities. The special problems arise from first, a low soil fertility caused by the exploitation of land over thousands of years without adequate attention to soil management and by various forms of soil erosion, secondly, an already high cultivated versus total land ratio thereby providing little scope for any substantial increase in the cultivated area and thirdly, most of the current cultivars being the products of selection for adaptation to adverse conditions of crop growth rather than for performance under good conditions of soil fertility and water management. Japan and Taiwan have been exceptional in developing earlier than most of the other countries in Asia, varieties of crop plants capable of responding to a good agronomy. Among the unique opportunities presented by tropical and sub-tropical agriculture are first, the possibility of growing several crops in a year and thereby of measuring productivity per

This is largely due to the habit of adding all forms of organic wastes to the soil, widely prevalent among the farmers of these countries.

Contd....p/2

day than per crop, secondly, the availability of large tapped and untapped water resources and thirdly, the feasibility of labour intensive farming practices. Recent plant breeding research has ~~hence~~ have aimed at exploiting the favourable features of ~~the Asian~~ our agricultural situation and of achieving a systematic destruction of the ceilings to high yields. As a result, varieties of crop plants possessing the type of morphological architecture and developmental pattern favourable for the efficient utilization of sunlight, water and fertilizer and consequently with a high yield potential have been evolved through the use of genetic tools in last few years. ~~in many countries of Asia. A few examples grouped according to the technique used, of some of the recent achievements of Indian geneticists and plant breeders and their significance in increasing food production are indicated in this paper.~~ article.

The scientific principles involved in their development and the long term implications of the release and spread of such varieties deserve wide understanding. I shall illustrate the possibilities and the problems with a few examples

I. ~~Rice~~ ~~Reconstruction of plant architecture:~~ High-yielding varieties of Rice.

I. ~~Rice:~~ Rice occupies nearly 35 million hectares in India but the average yield is only 1.1 tonnes per hectare, in contrast to over 4 tonnes per hectare in Japan. The varieties cultivated in India mostly belong to the sub-species *indica* of *Oryza sativa*. Some of the reasons for the low yield potential of our rice culture are : (a) the weak and tall straw of the *indica* varieties which makes the cultivation of rice under good conditions of soil fertility and the application of fertilizers difficult without causing lodging, (b) poor ~~photo-synthesis~~ trap of calories due to the extensive cultivation of rice during the monsoon season

Contd....p/3.

when the sky is cloudy during most parts of the day, (c) the season bound nature of most of our varieties which limits productivity per day, (d) poor utilization of sunlight due to the shading of lower leaves by the upper ones, (e) poor water management and (f) poor insect and disease control. Some years ago, Chinese Scientists discovered a spontaneous mutant in the variety Dee-gee-Woo-gen which had the following characteristics: (i) a dwarf plant habit, the plant attaining a height of about 60 cms; (ii) stiff and erect leaves, facilitating the maximum interception of sunlight, (iii) insensitivity to photoperiod (i.e., length of the day) enabling the cultivation of the crop in any season and (iv) absence of seed dormancy, rendering sowing possible immediately after harvest. Using this mutant, scientists in several parts of the tropics are now developing fertilizer- responsive and photo-insensitive varieties, which have revealed enormous possibilities for increasing the yields of indica rices. ~~This~~

Taichung Native 1, developed in Taiwan, is the first outstanding dwarf and photo-insensitive variety developed in indica rice. It was developed by crossing a tall indica, Tsai Yuen-Chung with Dee-gee-Woo-gen. The outstanding characters of this variety are : (a) stiff and upright leaves (b) dwarf plant height, (c) synchronous tillering habit, (d) photo-insensitivity, (e) drought resistance and (f) lack of seed dormancy. Its primary defect is a very high degree of susceptibility both to virus and bacterial diseases. At the International Rice Research Institute, in the Phillipines, numerous dwarf indica strains have been developed using the chinese discovery. Two of them

Contd....p/4.

IR-8 and IR-5 have done very well in several countries in South East Asia.

IR-8 is a selection from a cross made by H.M. Beachell during 1962-63 at the International Rice Research Institute, between Peta, a tall Philippines indica variety and Dee-gee-WOO-gen, Peta has in its parentage Latisail, an indica variety of Bengal. IR-5 was developed from a cross between Peta and Tangkai Rotan, a variety from Malayasia. IR-8 has chalky grains and its ~~the~~ cooking quality has been considered to be poor in most parts of Asia, a factor which is responsible for its being discarded from cultivation in many ~~regions~~ countries, so soon after its introduction

A dwarf variety with the basmati type of grain is currently under final stages of assessment at the Indian Agricultural Research Institute. This was developed through hybridization between a basmati variety from Dehra Dun and Taichung Native 1 followed by a series of backcrosses to basmati. This dwarf basmati strain combines fine grain quality with a high yielding ability. ~~The grain quality of IR-8 has also been considerably improved through mutation breeding.~~ Several other strains possessing both the ability to respond to fertilizer application and ~~acceptability~~ acceptable cooking quality ~~are now~~ will shortly become available

Japonica varieties: Several tropical japonica varieties developed in Taiwan such as Tainan 3, Taichung 65 and Kaohsiung 68 have done well in India and have yielded 5 to 7 tonnes per hectare. They are very resistant to the bacterial blight disease but have unfortunately grains which become sticky on cooking ~~sticky grains~~. This defect has been removed at the I.A.R.I. through the induction of indica mutants in Taichung 65 and Tainan 3. ~~This as well as the back-cross technique of breeding would help to obtain in a short time dwarf strains with the desirable grain quality.~~

Contd...p/5.

<u>Japonica</u> x <u>Indica</u> crosses : Crosses between <u>japonica</u> and <u>indica</u> varieties have been attempted during the last two decades but due to difficulties in getting a wide spectrum of recombination, it has not been possible to develop many varieties with the desirable characters of both the parents. Also, it is now apparent that morphological more than physiological factors limit the response to fertilizer application. There are, however, a few outstanding varieties which have resulted from this programme. ADT-27 developed in the Madras State from the cross Norin 8 (Japonica) x GEB 24 (Indica) has yielded on an average 5 tonnes per hectare in the Tanjore District of Madras State. This strain is now replacing the popular Kuruvai strain ADT.20. Sown in June or July, ADT-27 comes to harvest in 105 days after sowing. The grains are medium fine with white rice of good cooking quality. What is even more significant is the high protein content (about 11%) of ~~this~~ ADT 27, in contrast to about 7 to 8% protein found in most other rice varieties.

~~Thus,~~ The rice varieties incorporating the Dee-gee-Woo-gen dwarfing gene have proved to be capable of yielding 8 to 10 tonnes per hectare, while with the earlier tall varieties yields higher than 4 to 5 tonnes per hectare were seldom possible. ~~What is more important,~~ The season of rice cultivation can now be changed to suit the needs of maximum productivity, since the barrier imposed by photosensitivity on adjusting rice growing seasons has been broken and sowing and harvesting periods can now be altered so as to synchronise crop growth with low cloudiness and abundant sunshine. Inspite of these possibilities there has been little progress in increasing rice production in the country, because of ~~administrative action having preceded a wrong choice~~ the poor quality characteristics of the Taiwan and Phillipine rices and because of a lack of understanding of the crucial role of water management factors in controlling yield.

Contd....p/6.

Wheat production

~~2.~~ ~~Wheat~~: The per-hectare yield of wheat in India has remained stagnant at about 800 Kgs for over 30 years. The total wheat production, however, rose steadily from about 7.0 million tonnes in 1951 to about 12.0 million tonnes in 1964-65, thanks largely to an extension in the area under the crop. There are at present about 13.0 million hectares under wheat, out of which about 4 million hectares have assured irrigation facilities fed by either canals or tubewells and ordinary wells. Even in irrigated areas, the average yield has been of the order of only 1.3 tonnes per hectare.

Scientific wheat improvement work was initiated in the early years of this century at the Indian Agricultural Research Institute under the guidance of Sir Albert Howard. This work let to the development of varieties like NP 4 and NP 52 which were capable of yielding about 3 tonnes per hectare under good conditions of management. In 1935, Dr. B.P. Pal reoriented the programme so as to incorporate a high degree of resistance to stem, leaf and stripe rusts in the cultivated varieties. Some of the varieties resulting from this programme such as NP 710, NP 718, NP 770, NP 798 and NP 809 became quite popular among the farmers, since they could harvest grains only from these strains in years characterised by severe rust epidemics. Breeding programmes were also initiated in the different States of India and some notable varieties like C.591, C.518, C.273 and C.281 were developed in the Punjab by Mr. Ram Dhan Singh. These Punjab wheats led to a preference in

Contd....p/7

the grain market for bold, hard, amber and lustrous grains. Prior to their introduction in 1934, varieties with red grains were also widely cultivated and the preference for amber grains now prevailing was not in existence. Throughout the country, however, there was preference for hard and vitreous grains because such wheats make good chapatees (unleavened bread, the form in which wheat is consumed in India) and store better under primitive conditions of grain storage. The soft wheats are heavily damaged by grain weevils during storage in mud bins and there has hence been an unconscious selection for wheats with a high Pelshenke value (a unit of measurement of gluten strength). There are nearly 1.5 million hectares under the tetraploid wheats, *Triticum durum* and *T. dicoccum*, which are widely cultivated in many parts of peninsular India due to their drought resistance. The common bread wheat, *T. aestivum*, is the dominant wheat of the Indo-Gangetic plains and occupies about 11.5 million hectares.

In 1962, I made a study of the factors responsible for the yield stagnation as well as instability in the productionof this crop. The following appeared to be the principal factors involved in these phenomena. First, the morphological architecture and developmental rhythm of the tall varieties cultivated until then were not conducive to the crop being grown under good conditions of soil fertility. Secondly, the tall straw and the consequent low resistance to lodging rendered irrigation impossible after about February (wheat is sown in most of India in October-November and harvested in March-April). The temperature rises fast and

Contd.....p/8.

12:82

exceeds 30°C from March and hence the plants experience both atmospheric and soil drought during the grain development phase. It is hence that Sir Albert Howard remarked over 50 years ago that "wheat yield in India is a gamble in temperature". Thirdly, most of the common wheat varieties, with the exception of those bred at the Indian Agricultural Research Institute, were susceptible to rusts and loose smut, Whenever the farmers supplied more water and nutrition to the crop, the disease problem also became more severe. Finally, late rains and hailstorm and heavy wind were recurrent during late March and the tall varieties invariably lodged even under conditions of low fertility. An important consequence of lodging is a delay in maturity and the shifting of grain development to more unfavourable environmental conditions than normal. This analysis led to the conviction that dwarf wheat varieties are essential both for increasing the yield potential of this crop through the effective use of water and fertilizer and for destroying some of the factors causing instability in production from year to year.

EVOLUTION OF DWARF WHEATS:

The discovery in Japan of genes in the Norin wheat variety, which confer a dwarf and non-lodging plant habit, hence opened the door to the reconstruction of the morphology of the wheat plant. Several dwarfing genes were known for a long time in wheat, such as the S or C genes which govern the Sphaerococcum and Compactum

contd.......p/9

characteristics respectively. However, these genes produced, coincidentally with dwarfing, very dense and compact ears. The first strain to be identified with the desired combination of short plant height, lodging resistance and ear characters was Norin 10. This variety was one of a collection of Japanese wheats brought to the United States by Dr. S.C. Salmon in 1946. Three recessive genes for dwarfing, with additive effect, have so far been identified in this material.

Using the Norin dwarfing genes, the dwarf winter wheat variety, Gaines, was developed by Dr. O.A. Vogel in the Washington State, United States, in 1961. Simultaneously, dwarf spring wheat varieties with the Norin dwarfing genes were developed in Mexico by Dr. N.E. Borlaug and co-workers. In order to develop dwarf wheat varieties suitable for cultivation in India, the Indian Agricultural Research Institute, New Delhi, introduced in 1963 a large variety of dwarf wheat material from Mexico through the kind courtesy of the Rockefeller Foundation and the Mexican Ministry of Agriculture. In 1963-64, this material was grown and assessed at Delhi, Ludhiana, Kanpur, Pant Nagar, Pusa, Bhowali, and Wellington for the extent of their adaptation and reactions to the prevailing races of stem, leaf and stripe rusts. In addition to breeding material, bulk quantities of four commercial Spring Wheat Varieties, Lerma Rojo 64A, Sonora 63, Sonora 64 and Mayo 64, were also obtained from Mexico. The trials

Contd....p/10.

conducted with these varieties even in 1963-64 with 80 Kgs p N per hectare revealed that a new order of yield has become open in wheat. During 1964-65 the dwarf strains were tested under the All-India Coordinated Wheat Trials. In addition, they were subjected to detailed physiological, pathological, chemical and agronomic tests at the Indian Agricultural Research Institute. They were also grown in farmers' fields under the National Demonstration Project, which provided an opportunity to scientists to demonstrate new findings to farmers. On the basis of all the data collected two Mexican varieties, Lerma Rojo 64A and Sonora 64, were approved by the Central Variety Release Committee of the Government of India in 1965 for cultivation in the irrigated wheat areas of India.

Lerma Rojo is a late variety with a high degree of resistance to all the three rusts. It performs very well under timely sown conditions and in areas characterised by stripe rust epidemics. Sonora 64, on the other hand, is an early variety and is well suited for being grown in rotations like Maize-wheat, potato-wheat, rice-wheat and sugarcane-wheat. It has two genes for dwarfing and hence it is the most lodging-resistant variety so far released. Being early, it is suitable for cultivation under high fertility conditions in the eastern parts of Uttar Pradesh, Bihar, West Bengal, Rajsthan, Madhya Pradesh, Gujarat, Maharashtra, Orissa and Madras. Sonora 64 does not do well if sown before the middle of November in areas where the normal sowing time is late October or early November. It is susceptible to stripe rust and hence has not been recommended for areas where this rust appears in an epidemic condition. It is also highly susceptible to loose smut and a good seed sanitation programme is essential for keeping the incidence of this disease low.

Contd.....p/11.

BREEDING NEW DWARF WHEATS:

Varietal diversity as well as a rapid replacement of varieties are essential for sustaining high wheat yields over many seasons. From the advanced generation material received from Mexico in 1963, several selections such as S.227, S.307, S.308 and S.331 were found to perform very well. These strains have amber grains and a very high yield potential. The original material of S.227 received from Mexico segregated for resistance to leaf rust and selections for resistance were made. These selections were tested in coordinated trials with the help of the participating State Institutions. The highest yields in national demonstrations in 1965-66 and 1966-67 were obtained with S.227, which yielded respectively 68 and 82.0 quintals per hectare in a farmer's field in the Delhi State. Seeds of S.227, S.307, S.308 and S.331 were multiplied at Wellington, in the Nilgiri Hills, during the summer of 1966 and 1967 and these varieties were approved for general cultivation in 1967. A brief description of these new strains and the names given to them are given below:

KALYAN SONA: This is a selection possessing resistance to leaf rust made from the population of S.227 grown in 1963-64. Selections were made at the Indian Agricultural Research Institute, the Punjab Agricultural University, Ludhiana, and the U.P. Agricultural University, Pant Nagar. This is a strain with medium maturity, amber grains, profuse tillering and a very high yield potential. It is derived from the cross, Penjamo sib x Gabo 55. The chapatee and bread making properties are good and this strain is likely to become one of the most widely grown in the country. From

Contd....p/12.

the same cross, two strains named Sieto Cerros 66 and Mexipak 65 have been released in Mexico and Pakistan respectively. In Mexico, a sister selection with red grains is being grown commercially under the name Super-X. Similar sister selections are called Indus 66 in Pakistan and V.18 and P.V. 18 in India. Thus, this cross has yielded many outstanding selections characterised by a high yield potential and wide adaptability.

SONALIKA: This is a single gene dwarf derived from the Mexican cross (II54-388-An) x (Yt.54 x N 10 B) LR.III 8427 and the original material was received under the number S.308. The grains of this variety are bold and amber.It possesses resistance to all the three rusts and does well both under timely-sown and late-sown conditions. Selection for non-shattering habit was made at the Indian Agricultural Research Institute.

SAFED LERMA: This is also a single gene dwarf derived from the Mexican cross (Y 50 x N. 10.B) (L.52) LR^3. Since it is from material back-crossed thrice to Lerma Rojo 64A, it resembles Lerma Rojo 64A very closely in height, pigmentation and other characters. The main difference lies in the white semi-hard nature of this strain, in contrast to the red and soft grain of Lerma Rojo 64A.

CHHOTI LERMA: This is a white seeded, two gene dwarf derived from the Mexican cross (R64(Sib) x HUAR). It is highly resistant to lodging and has good resistance to all the three rusts.

Contdd.....p/13.

SHARBATI SONORA: The 2-gene dwarf wheat variety Sonora 64 introduced by the I.A.R.I. in 1963, has, as mentioned earlier, proved to be capable of yielding about 6 tonnes per hectare when grown properly. The seeds of this variety are, however, red in colour and hence fetch a lower price in the grain market (a difference of about Rs.20.00 per quintal exists in the price of red and amber coloured grains). The variety was hence subjected to mutation breeding in 1963 and an amber seeded mutant isolated from gamma ray treated material was approved for release by the Central Variety Release Committee in 1967, under the name "SHARBATI SONORA". Sharbati Sonora resembles Sonora 64 in all other respects except the quality and colour of grains. Besides having bold and amber seeds, Sharbati Sonora was found to possess on an average 16.5 per cent protein in contrast to about 14.0 per cent in the parent strain. Also, Sharbati Sonora has about 3 grams lysine in 100 grams protein, in contrast to about 2.4 grams lysine/100 grams protein in Sonora 64. It appears that a major factor for protein and lysine synthesis may be located near the gene concerned with grain colour. This mutant has helped to establish that protein quality and quantity can be coincidentally improved. This variety has also excellent bread making properties. Since Sharbati Sonora yields over 6 tonnes per hectare, it is also an index of the possibility of developing high yielding-cum-high quality varieties of cereals and other crops.

Contd....p/14.

In the Indo-Gangetic alluvial soils lodging occurs even with single and two-gene dwarf strains. This is partly because of the poor soil structure arising from the many ploughings (usually exceeding 10) which farmers give prior to the sowing of wheat and partly due to the occurrence of late rains and gale in the month of March invariably every year. Consequently, there is enormous interest now in varieties with 3 genes for dwarfing (called "Triple Dwarfs") and several such strains are in advanced stages of testing. The new varieties under development are non-lodging, highly resistant to the prevalent races of rusts and have grains with a high protein and lysine content.

COMBINATION BREEDING INVOLVING INDIAN & MEXICAN PARENTS:

The good adaptability of the Mexican Wheat varieties under Indian conditions made it possible to usher in the era of dwarf wheats in India sooner than it would have been possible otherwise. It should, however, be emphasised that the Mexican varieties and breeding materials have also proved very useful in hybridisation programme with Indian wheat varieties such as N.P. 875 and N.P. 852. Many Mexican and Indian parents combine very well and already more than 5,000 crosses have been made. It has been possible to develop strains from this hybridization programme, which combine the best attributes of both the parents. In particular, the grain characters and the chapatee-making quality of the

Contd....p/15.

Indian wheats have been combined with the photo-insensitivity, disease resistance and fertilizer responsiveness of the dwarf types. Several of these strains, which in preliminary yield trials have out-yielded the parental types, are now undergoing extensive multi-location tests. The breeders' assembly-line contains many new high yielding-cum-high quality varieties and an essential pre-requisite for yield advance and stability, namely varietal diversity and the rapid replacement of varieties, can be met. Dwarf varieties have also been developed in the macroni wheat, *T. durum*, and they are being tested for their yielding ability.

II. Exploitation of hybrid vigour:

In maize (*Zea mays*), Sorghum (*Sorghum vulgare*) and Pearl Millet (*Pennisetum typhoides*) which are cross-pollinated crops, the exploitation of hybrid vigour has helped in increasing by over 100% their yield potential. Eight different hybrids in maize, two in *Sorghum* and four in Pearl Millet have been released in India. In *Sorghum* and Pearl Millet, hybrid seed production involves the use of male sterile lines. All these hybrids are characterised by (a) ability to respond to high levels of fertilizer application (b) photo insensitivity and (c) suitability for being grown in rotations with other crops like wheat and rice. Brief descriptions of these hybrids and their yielding ability are given below:

Contd....p/16.

much superior to the others in these traits. The PER value of the protein of Sharbati Sonora was higher than that of the parent strain, Sonora 64.

The strength of gluten, as judged by the Pelshenke value, determines to a great extent the quality of chapatee (unleavened bread, the form in which wheat is largely eaten in India) and the resistance to weevils during storage. The Mexican semi-dwarf wheat variety, Lerma Rojo, yields over 5 tonnes per hectare in many parts of India and has a high degree of resistance to stem, stripe and leaf rusts. It has, however, red and soft grains, characters not liked both by farmers and consumers. Hence, a mutation breeding programme was taken up and amber-grain mutants were isolated (Varughese and Swaminathan, 1966). Many of these mutants had a much stronger gluten than the parent strain (Table 6). Pelshenke values higher than 120 are good for chapatee-making purpose.

b) Rice : The mutants with indica-type of grains isolated in the japonica variety T. 65 were tested for protein content. The data reveal that there is much scope for increasing the protein content of rice. The breeding behaviour of the high protein lines and PER values are now being studied.

~~IX.~~ C. Breeding for higher and stable yields under adverse environments :

In many parts of our country, ~~India and also in the other countries in Asia~~ the annual rainfall is below 40 cms and the distribution of

Contd....p/27.

the rainfall is skewed. Since there has been considerable progress in improving the yield and income of farms in irrigated areas, breeding research should aim at enhancing the income potential of farms in unirrigated and low rainfall areas also, if serious economic disparities and social tensions are not to arise. The approach of Indian plant breeders has been to develop new plant types for such dry areas, based on the indices of selection provided by physiologists. Thus, in wheat, branched types of <u>Triticum aestivum</u> are under development, since the primary way of increasing yield in unirrigated areas seems to be through an increase in the number of grains and the weight of grains in the main tiller. In the case of <u>Sorghum</u>, it has been found that a hybrid, CSH-1, exhibits both a higher yield and a greater stability in production, in comparison with varieties when grown in dry and unirrigated areas (Table 1). The data in Table 1 were collected by N. Ganga Prasad Rao and Harinarayana (1968) and represent grain yields obtained under rainfed conditions over a period of 4 years at 10-12 locations representing diverse environments. The years 1964 and 1967 received normal rainfall, while 1965 and 1966 were characterised by drought. Genotype x environment interactions were obtained by conventional analysis of variance. Using a model developed by Eberhart and Russel (1966, 1968), stability is described by three parameters - mean yield, regression of mean yield on an environmental index and deviations from

Contd....p/28.

regression. It is clear from the data that the hybrid CSH-1 is superior to the local varieties under good as well as adverse environmental conditions. ~~Barber et al., (1968) have suggested that the formation of hybrid enzymes may be responsible for the wider adaptability of heterozygotes and polyploids. Certain hybrid enzymes may be stabilized against environmental fluctuations and thus allow the plant to survive environmental extremes in the way found by McWilliam and Griffing (1965) in their study of the effect of hot and cold temperature shocks on hybrid and pure-bred maize.~~ Thus, Capitalising on heterozygote advantage could be an efficient genetic method of yield stabilisation under conditions of stress frequently met with in rainfed areas. The policy implication of this finding is that the cultivation of hybrids should be rendered feasible in unirrigated and moisture deficit areas. This is in contrast to the present policy of advocating their cultivation only in areas endowed with irrigation facilities.

~~**CONCLUSION:**~~

~~Recent advances in plant breeding have opened up a vast panorama of possibilities in improving the yield and quality of all plants of economic value. Mendel has thus provided the most potent tools with which Malthusian predictions can be belied.~~

~~MSS:nji~~

The future of high-yielding varieties