INDIA'S SUCCESS WITH DWARF WHEATS*

M.S. Swaminathan

Dr. M. S. Swaminathan was an Indian geneticist, agricultural scientist and an international administrator. He is renowned for his leading role in the Green Revolution in India, which caused a substantial increase in wheat and rice production, making India self-sufficient in food grains. He served as the Director General of the Indian Council of Agricultural Research and Principal Secretary of the Ministry of Agriculture and Irrigation.

In this article, Dr. Swaminathan provides a detailed account about the significant research findings in India in the 60s in the improvement of crop varieties, especially with the development and success of the Dwarf Wheat variety in India. The article takes us through a journey of how scientific wheat improvement started in the Indian Agricultural Research Institute (IARI) and led to the development of wheat variety with greater yield and resistance to diseases. It discusses how the discovery of genes which confer a dwarf and non-lodging plant habit in Japan opened the door to the reconstruction of the morphology of the wheat plant. The article elaborates how these varieties were tested in all the wheat growing states of India during 1963–64 and 1964–65, under the All-India Coordinated Wheat Improvement Project and how these varieties were subjected to detailed physiological, pathological, chemical and agronomic tests at the IARI. A brief descriptions of the newly developed strains that were successfully used during that time have also been provided in the article.

Keywords: Crop, Dwarf Wheat, Yield, Plant-Breeding, Genes, Disease-Resistance

During the last few decades, wheat yield in India have been stagnant at about 800 kg per hectare. Total wheat production, however, rose steadily from about 7 million metric tons in 1951 to about 12 million in 1964-65, thanks largely to an extension in the area under the crop. There are at present about 13 million hectares under wheat, of which about 4 million 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 metric tons per hectare.

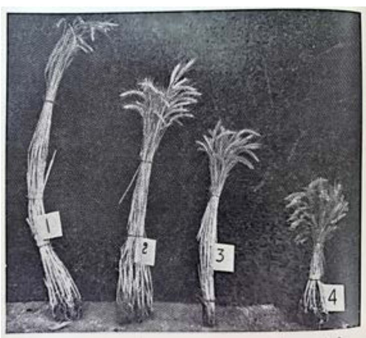

Fig. 1. Four Different Wheats: (1) Tall, (2) Single-gene Dwarf, (3) Two-gene Dwarf, (4) Three-gene Dwarf

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Scientific wheat improvement work started in the early years of this century at the Indian (then Imperial) Agricultural Research Institute, under the guidance of Sir Albert Howard. This work led to the development of varieties like NP4 and NP52, which were capable of yielding about 3,000 kg 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 NP710, NP718, NP770, NP798 and NP809 became quite popular and in years of severe rust epidemics, farmers could harvest grain only from these strains.

Breeding programmes were also initiated in the different states of India and some notable varieties like C591, C518 and C281 were developed in the Punjab by Ram Dhan Singh.

These Punjab wheats led to a preference in the grain market for bold, hard, amber and lustrous grains. Before their introduction in 1934, varieties of red grains were also widely cultivated and the present preference for amber grain did not exist. Throughout the country, however, there was preference for hard and vitreous grains both because such wheats make good chapatis (unleavened bread, the form in which wheat is consumed in India) and because they 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 therefore been an unconsicious selection for wheats with a higher 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 because of their resistance to drought. The common bread wheat, *T. aestivum,* is the dominant wheat of the Indo-gangetic plains.

In 1961, was made a study of the factors responsible for the yield stagnation as well as instability in the production of this crop. The following appeared to be the principal factors involved. First, the morphology and development of the tall varieties being cultivated were not conducive to the crop being grown under good condition of soil fertility. Secondly, the tall straw and the consequent low resistance to lodging made irrigation impossible after about February (wheat is sown in most of India in October-November and harvested in March-April); the temperature rises rapidly and exceeds 30°C from March, so the plants experience both atmospheric and soil drought during the grain development phases. This is why Sir Albert Howord commented over 50 years ago, "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 (IARI), were susceptible to rusts and loose smut, and whenever more water and nutrients were supplied to the crop, the disease problem became more severe. Finally, late rains and hail storms and heavy wind are 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 the crop through the effective use of water and fertilisers and for destroying some of the factors causing instability in production from year to year.

Genes for Dwarfing

The discovery in Japan of genes in the Norin wheat variety, which confer a dwarf and non-lodging plant habit, opened the door to the reconstruction of the morphology of the wheat plant. Several dwarfing genes had for long been known in wheat, such as the S or C genes which govern the Sphaerococcum and Compactum characteristics respectively. These genes, however, produced coincidentally with dwarfing, very dense and compact ears. The first variety which appears to have had 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 Washington State, USA, in 1961. Similarly, dwarf spring wheat varieties had been 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 introduced in 1963, a large variety of wheat material containing the Norin dwarfing genes from mexico, through the courtesy of the Rockefeller Foundation and the Mexican Ministry of Agriculture. In 1963, the IARI distributed this material to several wheat breeding centres in order to assess the extent of their adaptation and reactions to the races of stem, leaf and stripe rusts prevalent in the country.

In addition to breeding material, bulk quantities use of commercial spring wheat varieties, Lerma Rojo 64A, Sonora 63, Sonora 64 and Mayo 64, were also obtained. These varieties were tested in all the wheat growing States of India during 1963-64 and 1964–65, under the All India Coordinated Wheat Improvement Project. In addition, they were subjected to detailed physiological, pathological, chemical and agronomic tests at the IARI. On the basis of the data obtained two of these varieties, Lerma Rojo 64A and Sonora 64, were approved by the Central Variety Release Committee of the Indian Council of Agricultural Research in 1965 for cultivation in irrigated areas.

Lerma Rojo is a later 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 growing in rotations like maize- wheat, potato-wheat, rice-wheat, sugarcane- wheat, etc. (See Tables 1 and 2). It has two genes for dwarfing and hence is the most lodging-resistant variety so far released. Being early, it is a safe variety for cultivation under high fertility conditions in the eastern parts of Uttar Pradesh, Bihar, West Bengal, Rajasthan, 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 later October or early November. It is susceptible to stripe rust and hence has not been recommended for areas where this rust is epidemic.

Table 1: Productivity Per Day in Some Wheat Varieties

Variety	Days in the Field	Productivity (kg/ha/day)
NP 880	151	17.1
Lerma Rojo	153	24.8
S. 227	154	34.2
Sonora 64	133	42.5

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 S227, S307 and S308 have been found to perform very well in the Northern Plains of India. These strains have amber grains and a very high yield potential. The original material of S227 received from Mexico segregated for resistance to leaf rust and resistant selections were made. In national demonstrations in 1965–66 and 1966–67, the highest yields were obtained with S227, which yielded respectively 6,800 and 8,200 kg per hectare in a farmer's field in the Delhi State. S307 is a derivative of a cross involving Lerma Rojo and the Japanese dwarf strain Norin 10-B. Seeds of S227, S307 and S308 were multiplied at Wellington, in the Nilgiri Hills, during the summers of 1966 and 1967 and these varieties were approved for general cultivation in 1967. Brief descriptions of these new strains and the names given to them are given below.

Kalyan Sona: A selection possessing resistance to leaf rust made from the population of S227 grown in 1963–64. Selections were made at the IARI, the Punjab Agricultural University, Ludhiana, and the U.P. Agricultural University, Pant Nagar. Kalyan Sona 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 chapati and bread making properties are good and this strain is likely to become one of the most widely grown in the country. From the same cross, a variety named Sieto Cerros 66 has been released in Mexico and a strain named Mexipak 65 in Pakistan. In Mexico, a sister selection with red grains is being grown commercially under the name Super-X. The same sister selection is called Indus 66 in Pakistan and VI8 and PV18 in India. Thus, this cross has yielded many outstanding selections characterised by a high yield potential and wide adaptability.

Sonalika: A single gene dwarf derived from the Mexican cross (II 54-388-An) x (Yt. 54 x N 10 B) LRIII 8427; the original material was received under the number S308. The grains of this variety are bold and amber. It is resistant to all three rusts and does well both under timely sown and late sown conditions. This selection was made at the IARI.

Safed Lerma: Another 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 semihard nature of this strain, in contrast to the red and soft grain of Lerma Rojo 64A.

Chhoti Lerma: A white seeded, two-gene dwarf derived from the Mexican cross [R64 (Sib) x HUAR]. It is highly resistant to lodging and has high degree of resistance to all three rusts.

Sharbati Sonora: The two-gene dwarf wheat variety Sonora 64 introduced by the IARI in 1963 has, as mentioned earlier, proved to be capable of yielding about 6,000 kg per hectare when grown properly.

However, the grain is red and so fetches a slightly lower price in the grain market. The variety was subjected to mutation breading in 1963 by Dr. G. Varughese and myself and an amber grained mutant, isolated from gamma ray treated material, was approved for release by the Central Variety Release Committee in 1967, under the name Sharbati Sonora. This variety resembles Sonora 64 in all respects except the quality and colour of the grain. Besides having bold and amber seeds, Sharbati Sonora was found to possess on an average 16.5 per cent protein in contrast strain to about 14 per cent in the parent strain.

Table 2: Wheat Yield in Rotations Involving Late Sowing

Location	Rotation	Wheat Variety	Date sown	Yield (Quintal/hectare)*
Delhi	Sorghum-wheat	Sonora 64	29.12.64	42.4
Jullundur	Potato-wheat	Sonora 64 Lerma Rojo Sonora 64	2.1.66 2.1.66 15.1.66	40.9 34.4 36.2
Samastipur	Rice-wheat	Sonora 64	5.12.66	37.1
Darbhanga	Rice-wheat	Sonora 64	19.12.65	25.5
Shahbad	Rice-wheat	Sonora 64	29.12.65	23.2
Delhi	Rice-wheat	Sonora 64	4.12.65	55.3

*1 Quintal = 100 kg

Table 3: Effects of Irrigation Applied at Diffrent Stages of Dwarfs Wheat, Sonora 64

Treatmet	Stages of Growth						Total Number of Irrigations	Yield (Quintal/ hectare)
	Crown Root	Late Tillering	Jointing	Boot	Floweing	Dough		
1	1	1	1	1	1	1	6	51.4
2	1	1	0	1	1	1	4	51.3
3	1	1	0	0	1	1	4	52.3
4	0	1	0	1	1	1	4	44.0
5	0	1	1	1	1	0	4	45.2
6	0	1	0	1	1	0	3	42.3

Critical difference at 5%=5.9
1 Indicates irrigation given
0 indicates irrigation not given

In addition, Sharbati Sonora has about 3 g lysine in 100 g protein in contrast to only about 2 glysine per 100 g protein in Sonora 64. It appears that a major factory for protein and lysine synthesis may be located near the gene concerned with grain colour. This mutant has helped to disprove the idea that protein quality and quantity cannot be improved at the same time. Since Sharbati Sonora yields over 6,000 kg per hectare, it is also a symbol of the possibility of developing high yielding-cum-high quality varieties of cereals and other crops. This variety has also excellent bread making properties.

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 ten) which farmers carry out before sowing wheat and is partly due to the invariable occurrence of late rains and gales in March. Consequently, there is enormous interest now in varieties with three genes for dwarfing (called 'triple dwarfs') and several such strains are in advanced stages of testing. All the new varieties are non-lodging, highly resistant to the prevalent races of rusts, and have grains with a high protein and lysine content.

New Agronomy

When the dwarf wheats were first tested extensively (in 1963–64) it became evident that certain fundamental changes in cultural practices were needed to get the best out of them. First, sowing had to be shallow (not deeper than 2 in) or the coleoptile could not penetrate the soil. Secondly, irrigation had to be given about 16 days after sowing, at the time of the initiation of the crown roots, otherwise the yield was considerably depressed. This is due to the synchronised nature of tiller development in these varieties, a factor which gets disturbed when irrigation is given late, as used to be done with the earlier tall varieties (see Table 3). The seed rate also had to be adjusted according to the tillering habit of the strain. When the wheat was sown in December or January, covering seeds with farmyard manure led to an increase in soil temperature and to a more rapid germination and growth. Sowing in a north-east to south-west direction resulted in the maximum interception of sunlight and promoted more vigorous growth.

Thus, a considerable degree of sophistication in the agronomic practices and a greater attention to the qualitative aspects of the use of inputs became essential. What is most interesting and encouraging is that the Indian farmer has taken to all these practices with a zeal and speed which have baffled conventional economists and administrators.

Fig. 2. India's 1968 Wheat Revolution Commemoration Stamp Produced To mark the country's Breakthrough in Wheat Production. The Stamp Depicts three Stalks of Wheat and the IARI New Delhi and Includes Histogram comparing Indian Wheat Production in 1951 and 1968

Yields in Unirrigated Areas

The rapid spread of high yielding varieties in irrigated areas has widened the gap in the income potential of irrigated and unirrigated lands. Research aiming at increasing the yield of wheat and income of farmers in unirrigated and low rainfall areas has indicated certain practices which help in improving yields and production in such areas.

First, deep ploughing helps to conserve moisture and enables two crops a year to be taken. Secondly, spraying with urea helps to increase yield by over 25 per cent in wheat. Scientist at the IARI have found that over 30 per cent concentration of urea can be safely applied to wheat by breaking down the particle size of urea in a low volume sprayer. This has rendered aerial spraying of urea possible in moisture-deficit areas and this can be provided as a government service.

Since under conditions of low moisture tillering is very much reduced in wheat and barley, the yield has to come from the main tiller. IARI physiologists have shown that by increasing the number of grains per ear in the main stem it is possible to increase the yield of wheat in dry areas. A special variety of wheat with branched ears like sorghum is therefore under development for dry areas. Also, hybrids between rye and wheat are under development which might combine high yield with nearly 20 per cent protein content.

Fig. 3. A striking example of resistance to lodging. The two-gene dwarf wheat on the left lodged after late rains in march, while the three-gene dwarf on the right side

With the earlier tall varieties, about 3,000–4,000 kg per hectare was the upper limited of the yield that could be easily obtained in irrigated areas. With the introduction of the dwarf varieties, this upper limit has risen to 7,000–8,000 kg per hectare. The new varieties now in the breeder's assembly line at the IARI belong to the following categories.

Triple Dwarfs: These have three genes for dwarfing and will not lodge even under very adverse conditions. Triple dwarfs combining high yield, excellent grain quality and a high degree of resistance to rusts are now in the final stages of assessment and multiplication.

Rye and Wheat hybrids: These have very long ears and may yield well both in irrigated and dry areas. In addition rye wheat (Triticale) has nearly 20 per cent protein and a high lysine content.

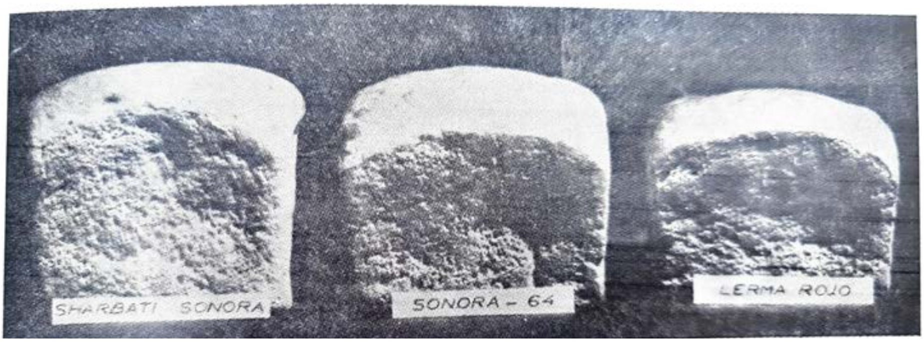

Fig. 4. Bread made from the same quality of flour from three different wheats demonstrate variation in loaf volume

Hybrid Wheat: As in maize, sorghum and pearl millet, research aiming to exploit the phenomenon of hybrid vigour is in progress in wheat. Such research was made possible by the discovery of male sterility in some wheat strains by Japanese workers.

Branched Wheat: A mutation for branching was induced in the variety NP 797 by gamma ray treatment. This has made the development of branched wheat varieties possible. Such varieties will have three to four times as many grains per ear as the varieties now grown and will greatly enhance the yield of wheat in both irrigated and dry areas. Branching is not known to occur in nature in bread wheats, but it occurs in one species of the wheat family identified in Egyptian mummies *(Triticum turgidum* var. *mirabile).*

Thus, in the immediate future the prospects are bright for developing wheats which can yield about 10,000 kg per hectare.

Dwarf and high yielding varieties have been developed in *durum* (macaroni) wheat, which is cultivated extensively in Madhya Pradesh and Mysore.

India is frequently referred to abroad as a country in which research and extension function without proper coordination. While there is some basis for this comment, few people are aware that India today holds the world record for the speed with which a significant research finding has been applied in the field. During the winter 1963–64, the IARI introduced wheat varieties containing the 'Norin' dwarfing gene from Mexico on the basis of the author's theory that dwarf varieties were essential for breaking down the barriers to high wheat yields. These were thoroughly tested all over the country during 1963–64 and 1964–65, and sufficient data to convince the Government of the wisdom of importing large quantities of seeds of two varieties were presented in June, 1965. That year 250 metric tons of seeds were imported, and 18,000 metric tons in 1966. As a result, we had nearly 400,000 hectares under dwarf wheats during 1966–67 and about two million hectares during 1967–68. There is no parallel for such rapid spread of new varieties in the world, and this great achievement has stimulated Turkey and Pakistan to take similar action this year. The wheat harvest of 1967–68, is estimated at over 17 million metric tons, in contrast to the seven million harvested in 1951–52, when the first Five Year Plan was initiated.