

BREEDING RICE FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

Current problems of current high-yielding rice varieties are discussed in relation to sustainable agriculture, and rice breeding strategies are reviewed. These include heterotic F_1 hybrids which have a higher output under low inputs, types with staggered heading for a high yield potential, and durable disease resistance. Difficulties in improving the grain quality of high-yielding varieties are discussed.

INTRODUCTION

During the past three decades, plant breeders have greatly contributed to the development of high-yielding crop varieties to meet the food needs of a growing population. Breeders have changed the morphology and physiology of crop plants, and incorporated desirable traits and resistant gene(s) into traditional varieties while stabilizing or increasing crop production. In most rice-growing countries, the primary breeding objective has been a high yield potential. The incorporation of the semidwarf gene into traditional tall, leafy rice varieties has made possible dramatic yield increases in the major rice growing countries (Table 1). The semidwarf rice variety IR 36 and other IR lines have been intensively used in national breeding programs for the development of high-yielding varieties. These are now planted in 60% of the world's rice land. In Korea, Tongil-type varieties derived from crosses between IR lines and Japonica varieties give yields 30% higher than the leading traditional varieties.

High-yielding varieties have made a great contribution to the world's food supply, but they also have several major problems. The high yields of these varieties can only be attained with a high level of inputs, in particular heavy applications of fertilizer (Fig. 1). This has led to problems associated with pest outbreaks in certain areas, while increased rice production has resulted in lower rice prices.

Although numerous improved high-yielding varieties have been released to farmers over the past few decades, little attention has been paid in rice varietal improvement to any concept of sustainable rice production. Particularly in countries like Korea,

which are self-sufficient in rice, it is time for rice breeding strategies and objectives to change their focus and emphasize sustainable rice production which is appropriate to local farming systems and their economic and social background.

BREEDING STRATEGIES

The ultimate goal of crop breeding is to develop varieties with a high yield potential and desirable agronomic characteristics. In rice breeding, the most important qualities sought by breeders have been high yield potential; resistance to major diseases and insects; and improved grain and eating quality. However, there seems to be some conflict between these aims. Emphasis on high grain quality tends to result in unstable yields. Conversely, too much emphasis on disease and insect resistance and stable yields leads to poor grain quality. Hence, breeding efforts should concentrate on varieties with the potential to minimize yield losses under unfavorable conditions, and to maximize yields when conditions are favorable. The following breeding approaches should be emphasized in producing varieties for sustainable rice production.

- High-yield potential under low inputs.
 - Heterotic F_1 hybrid
 - New plant type
- Premium grain and eating quality to meet consumer demand, and to provide grain suitable for processing.
- More genetic diversity.
- Durable host resistance to major diseases and insects.
- Wider range of growth duration for vari-

Table 1. Rough rice yield in selected Asian countries, World Rice Statistics, IRRI, 1990

Country	Yield ton/ha			% increase over 1970	
	1970	1977	1987	in 1977	in 1987
Bangladesh	1.69	1.94	2.24	115	133
China	3.42	3.64	5.41	106	158
India	1.68	1.96	2.29	117	136
Indonesia	2.38	2.79	4.04	117	170
Japan	5.63	6.17	6.19	110	110
South Korea	4.55	6.79	6.02	149	132
Myanmar	1.70	1.95	3.04	115	179
Philippines	1.75	2.00	2.62	114	150
Thailand	2.02	1.59	2.02	79	100
Vietnam	2.15	1.94	2.70	90	126

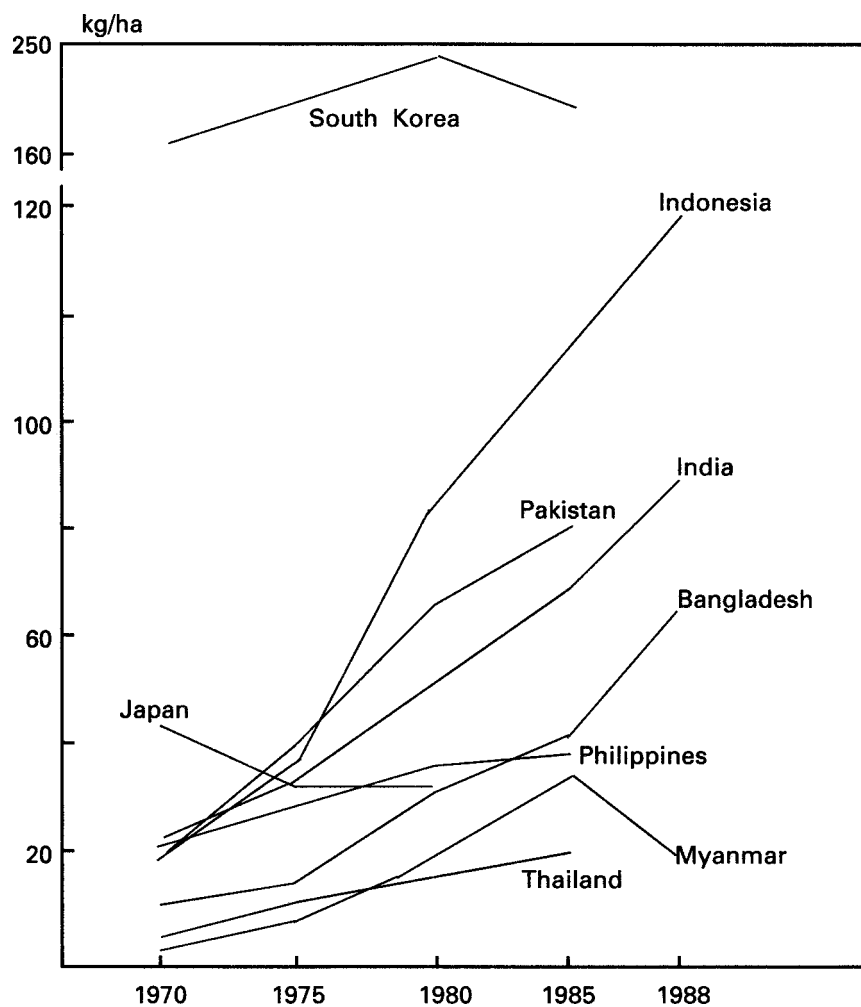


Fig. 1. Consumption of fertilizer (N, P₂O₅, K₂O) applied to rice, World Rice Statistics, IRRI, 1990

- ous purposes.
- Proper levels of tolerance to environmental and climatic stresses in specific areas.

HIGH YIELD PRODUCTION UNDER LOW INPUTS

For sustainable agricultural production, attention must focus on the development of high-yielding crop varieties which have premium quality under low inputs. At present, breeders are examining a wide range of genetic resources towards this end.

Experiments have indicated that average yields of current rice varieties given no nitrogen application are only 70% of those given an optimum N application of 150 kg N/ha (Fig. 2). However, F_1 hybrids are one possible way in which we may achieve yield increases with less applied nitrogen in the near future. A study of the growth of rice hybrids given five levels of nitrogen fertilizer showed that positive heterobeltiosis in plant weight increased linearly from no nitrogen to 150 kg of nitrogen per hectare (Fig. 3). The highest heterobeltiosis* in plant weight was found when no nitrogen was applied, followed by 75 kg/ha and 150 kg/ha of nitrogen. In a comparative study of nitrogen response in F_1 hybrids and conventional semidwarf varieties, F_1 hybrids were observed to have higher yields when no nitrogen was applied (Fig. 4). This suggests that hybrids attain a higher yield at lower nitrogen applications than do conventional semidwarf varieties. In Mainland China, about 14 million ha are currently planted in hybrid rices, but the use of hybrids in other areas would depend on whether seed production was economical, and on whether grain quality was found acceptable by consumers (Akama and Maruyama 1990). Recently, photoperiod-sensitive (PGMS) and thermosensitive male sterility (TGMS) systems are giving promising results in seed production (Virmani *et al.* 1990). It has been suggested that one approach to achieving high yields with low inputs may be to emphasize varieties with the characteristics of staggered heading during the flowering stage (Kim and Virmani 1989). A major barrier at present to even higher yields is that varieties with a large number of spikelets per panicle tend to have a lower percentage of filled spikelets, caused by nutritional competition between grains. Staggered heading of tillers over a prolonged period, rather than simultaneous heading within a short period, may overcome nutritional competition between grains caused by an insufficient supply of carbohydrates as they simultaneously develop (Table 2). Furthermore, staggered

flowering may avoid infection with disease and other unexpected stresses at the flowering stage. If heading covers a very long period, there may be management problems. Recently, the efforts of the International Rice Research Institute (IRRI) have been concentrated on modifying the plant type of modern high-yielding varieties in order to increase the yield potential. This new type has 4-5 productive tillers and large panicles, and is suitable for direct seeding (Khush and Aquino 1990).

There seems to be some difficulty in adapting current high-yielding varieties, which are very responsive to nitrogen, to a sustainable farming structure, but heterotic F_1 hybrids and new plant types will be available in the near future and are likely to be much more suitable. Furthermore, high-yielding varieties can be expected to increase farmers' incomes, since they will permit more diversified cropping systems as less land is required for rice.

RESISTANCE TO INSECTS AND DISEASES

Needless to say, host resistance to various biotic stresses is a very important aspect of high yields, and can be expected to play a significant role in sustainable rice production. Intensive efforts have been made over the years to incorporate resistant gene(s) into improved varieties, and there are now numerous varieties resistant to rice blast, bacterial blight, various virus diseases, and planthoppers. Some varieties possess multiple resistance to diseases and insects, but resistance in most varieties is controlled by a single gene and lasts only a few years, after which they become susceptible to serious disease or pest outbreaks.

For example, most Tongil-type varieties grown widely in Korea during the 1970s had a high level of resistance to rice blast disease, but in 1977 large areas planted in these varieties were severely damaged by blast (Ryu *et al.* 1987). In contrast, varieties with the Xa 4 gene resistant to bacterial wilt have been grown in the Philippines for the last 15 years, and continue to be resistant. If a resistant variety becomes susceptible, a new variety with different gene(s) for resistance should be waiting ready for distribution to farmers (Khush and Virmani 1985). However, it is difficult to predict in advance which variety will suddenly need to be replaced, and it is difficult to release a new variety within a short period. Furthermore, there may not be a wide enough range of genetic resources to provide a new variety with different genes. It is extremely difficult to identify polygenic resistance and incorporate it into improved germplasm (Khush and Virmani 1985).

Current studies on host resistance to crops emphasize the durability of resistance (Ikehashi and Kiyosawa 1981, Ahn 1982, Lee *et al.* 1989). Polygenic traits rather than absolute resistance would be preferable in sustainable agricultural production (Hauptli *et al.* 1990). Some breeders believe that resistance to pests or other stresses is linked with low yield and poor grain quality. This relationship must be studied further.

GRAIN QUALITY OF HIGH-YIELDING VARIETIES

Improvements in rice quality are very important in meeting the demands of consumers for healthy, high-quality food. Most rice breeders feel that improved high-yielding varieties in recent years have premium quality in terms of grain size, shape, appearance and palatability. However, consumers are still not satisfied with the grain quality of these

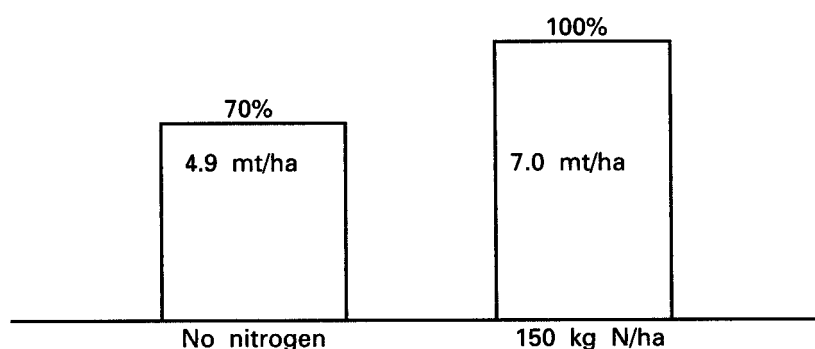


Fig. 2. Average grain yield production under no nitrogen and 150 kg/ha in 1987, 1988 and 1990, Honam Crops Exp. Sta., RDA, Korea

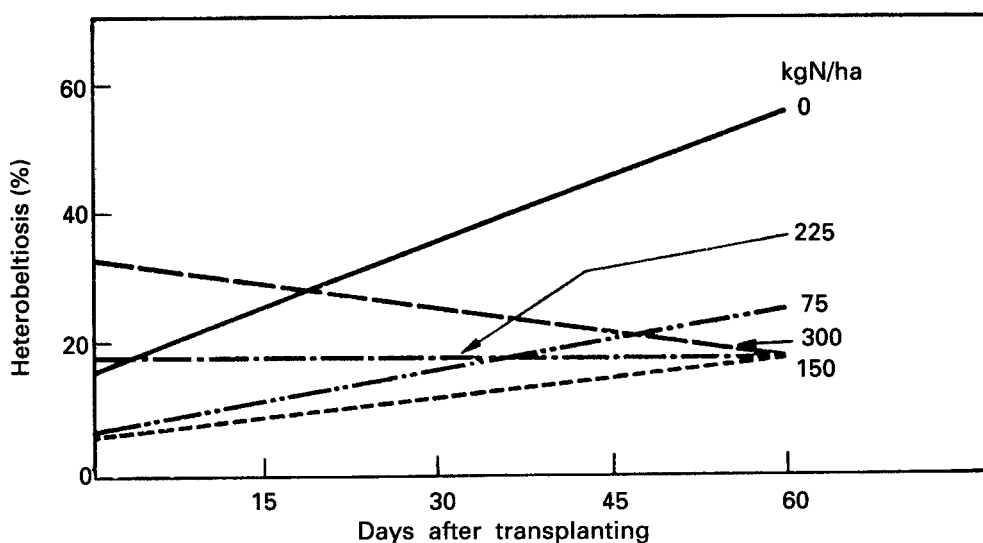


Fig. 3. Change in heterobeltiosis on dry weight 60 days after transplanting under five N levels at 30 x 15 cm spacing

Source: Kim and Rutger 1988

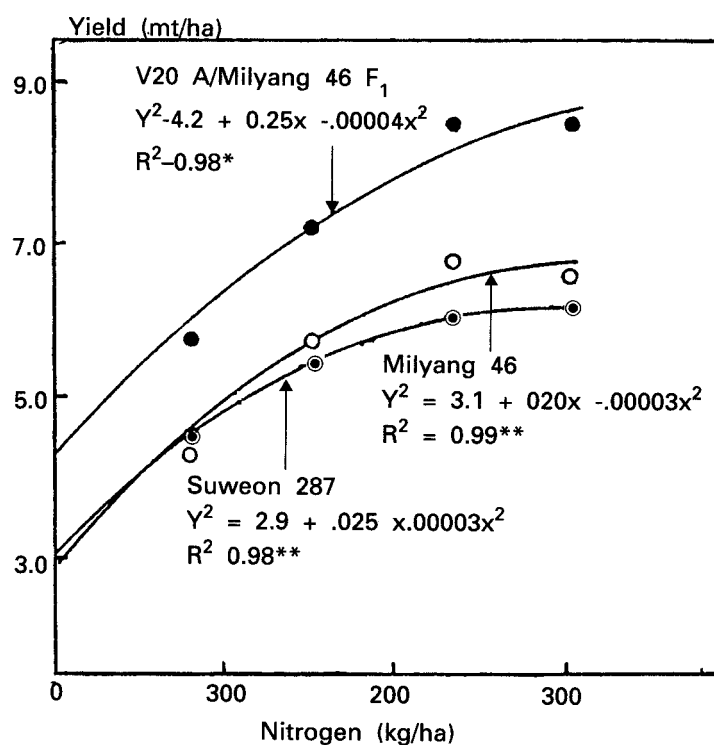


Fig. 4. N response of F1 rice hybrids and elite inbred cultivars for yield

Source: Virmani *et al.* 1990

Table 2. Comparison of grain yield and filled spikelet percentage, with staggered heading of three Tongil-type varieties/lines

Variety/line	Grain yield (mt/ha) ¹	Filled spikelets ¹ (%)	Days from initial to full heading ²
Iri 313	7.68	78	17 - 20
Tongil	7.13	71	13 - 16
Yushin	6.58	51	6 - 8

1) Average under two nitrogen levels

2) Estimated through the field observation

Source: Kim and Virmani, 1989

varieties. There are many difficulties in evaluating consumer preferences, which vary widely from country to country and from person to person. However, consumers generally feel that even the best quality grain of improved high-yielding varieties is not as good as the best quality traditional varieties. Many traditional varieties in both the tropics and the temperate zone have excellent cooking and eating quality, but a

low grain yield (Khush and Juliano 1985). For many years, breeders have focused their attention on quality improvement, but without success. There seems to be some unknown genetic barrier to incorporating this trait into high-yielding varieties. At present, it is not possible to be very optimistic that we shall be able to develop high-yielding varieties with quality as good as that of traditional

varieties, but our efforts continue, as does our work to develop high-yielding varieties with various grain characteristics suitable for processing.

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DISCUSSION

In the discussion following the paper presentation, Dr. Hsieh discussed the effective use of nitrogen by rice varieties at very low levels of inputs, and pointed out that in Taiwan only 25% of fertilizer N applied to rice was taken up by the plant, while the rest was leached out into underground water. This was not only a waste of fertilizer, but a cause of environmental pollution. Genotypes which absorb more applied nitrogen from the soil are obviously desirable, and Dr. Hsieh wondered how breeders could screen for N efficient varieties. He added that breeders tend to be more concerned with plant physiology, and the incorporation of N into protein and starch, the translocation of starch, and similar characters. Dr. Hsieh also felt that the difficulty of developing high-quality rice from current high-yielding varieties applied to Indica rather than Japonica type rice varieties. He pointed out that new hybrids in Japan have a better flavor and quality than the old traditional varieties, and there were similar examples from Taiwan. Their yield was good, although admittedly not as high as that of the best high-yielding varieties, but their flavor was excellent. Dr. Kim replied that most Korean consumers do not find Indica type rice very palatable, but in any case he did not think that Japonica rice had a higher potential. He suggested that the apparent conflict between high quality and high yield potential might reflect some unknown genetic linkage between high yield and poor grain quality. Some traditional Korean varieties had high quality but low yields, and breeders had not been able to achieve similar quality in the varieties developed in recent years.

Dr. Umali expressed his approval that Korean breeders are not aiming for a universal variety, and felt it was much better to breed different varieties for different environments. He reminded participants that the variety IR 8 had lasted only four years, because its short straw was not popular among farmers, who needed the straw to feed to their livestock. He also pointed out that modern varieties can become susceptible to disease in only four or five years, even when they have multiple resistance. This is a major problem, since it might take ten or fifteen years to breed and test a new variety for distribution to farmers. Dr. Kim suggested that resistance might still remain in the variety, but that meanwhile the disease may have mutated and evolved into a new type. He proposed that farmers should rotate different varieties to try and slow down the evolution of rice diseases.