Developing New Crop Varieties Tolerant to Stress and Low-Input Conditions

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Abstract

During this century the yield potential of many cereal crops trebled. The high- yielding potential was realized mainly by improving the plant type of the crops which enabled efficient use of solar energy and fertilizers as symbolized by the so-called ideotype. This type which is characterized by a high-yielding capacity can be achieved only under ideal conditions of irrigation, fertilizer application, pest, disease and weed control, namely under a high input-high return (H-H) system. This H-H system has been adopted in many parts of the world where intensive use of resources was possible and technology was available, and the H-H system has contributed significantly to feeding the world population.

In contrast, in the marginal production areas and developing countries where financial and technological supply is limited, we have to develop a low input-medium return (L-M) system.

For saving resources input, e.g., fertilizers, agricultural chemicals, irrigation, etc., new crop varieties adapted to L-M system should be stress-tolerant and fertilizer-responsive. Beside the biotic stress tolerance, abiotic stress tolerance such as drought tolerance, salt tolerance, etc. is especially important for the L-M system. Compared with the H-H system in which high-yielding varieties must be tolerant to heavy fertilizer application, varieties have to respond significantly to a small amount of fertilizer application in the L-M system.

Since 1988, using about 10,000 accessions of barley, wheat, rice, soybean and buckwheat, the author has conducted an evaluation of crop varieties which are adapted to the L-M system under semi-arid and saline conditions in China, and succeeded in selecting several promising varieties adapted to the L-M system. Generally they showed vigorous vegetative growth and were stress-tolerant.

At the Barley Germplasm Center, Okayama University, we have preserved about 8,000 accessions of wild and cultivated barley. Tolerance to salt, flooding, pre-harvest sprouting, deep seeding, several kinds of diseases and aphids was evaluated in these accessions. Remarkable varietal differences in stress tolerance indicated the importance of the collection and utilization of genetic resources for future plant breeding.

Introduction

During this century the yield potential of many crops trebled. In the developed countries, this yield increase started 100 years ago while it has occurred recently in the developing countries. This "Green Revolution" was realized mainly by improving the plant type of crops which enabled the efficient use of solar energy and fertilizers. This type of high-yielding capacity, or ideotype of the crops, can be achieved only under ideal conditions of irrigation, fertilizer application, pest, disease and weed control. This type will be referred to as high input-high return (H-H) system. This H-H system was achieved in many parts of the world where intensive application of resources and advanced technology were available, and the H-H system has

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contributed significantly to feeding the world population.

In contrast, in marginal areas and developing countries where financial and technological resources are limited, a low input-medium return (L-M) system should be developed. This L-M system will contribute to low-input sustainable agriculture too.

For saving resources input, e.g., fertilizer, agricultural chemicals, irrigation, etc., new crop varieties adapted to the L-M system should be stress-tolerant and fertilizer-responsive. In addition to biotic stress tolerance, abiotic stress tolerance such as drought tolerance, salt tolerance, etc. is especially important for the L-M system. High-yielding varieties must be tolerant to heavy fertilizer application in the H-H system, whereas, varieties have to respond drastically to a small amount of fertilizer application in the L-M system.

Case study in China

Since 1988, using about 10,000 accessions of barley, wheat, rice, soybean and buckwheat, the author has conducted an evaluation of the crop varieties adapted to the L-M system under semi-arid and saline conditions in Huangtu Plateau and Huang-Huai-Hai Plain (mid-stream and downstream of the Yellow River) in China.

These accessions that were introduced to the two sites were continuously evaluated for ten seasons and several promising entries adapted to the L-M system were selected. Generally they showed vigorous vegetative growth and were stress-tolerant.

Importance of potential vigor and fertilizer response

For preventing lodging under heavy fertilizer application, crop varieties adapted to the H-H system generally belong to the semi-dwarf type. However semi-dwarf varieties show an extremely poor growth under limited fertilizer and water application, because they have been selected for adaptation to heavy application of fertilizer and irrigation.

Crop varieties adapted to low input conditions generally show a high potential vigor. The Japanese rice variety Norin 18 which was released in 1941 when the fertilizer supply was restricted because of the Second World War was adapted to a low input of fertilizers.

Genetic variation in stress tolerance

Stress tolerance is a key character for low input sustainable agriculture.

At the Barley Germplasm Center, in Okayama University, we have preserved about 8,000 accessions of wild and cultivated barley. Resistance to diseases, such as scab, net blotch, powdery mildew, barley yellow mosaic was evaluated in thousands of accessions and the major genes controlling the resistance were identified.

Genetic variation in aphid resistance was also evaluated in thousands of accessions. Wild accessions were generally resistant but no major gene for the resistance has been detected.

In addition to the biotic stress tolerance, abiotic stress tolerance such as tolerance to drought, salt, acidity, wet injury is especially important for the L-M system to save the resources input.

Tolerance to flooding, pre-harvest sprouting, deep seeding and salt was evaluated in thousands of accessions. Outline of varietal differences in the traits is as follows:

Water sensitivity

In East Asia where barley is grown under the monsoon climate, flooding tolerance is very important.

Flooding tolerance at the time of germination is especially important for malting barley because uniform germination is required for malt production. This character is referred to as "water sensitivity" . Water sansitivity is defined as the reduction of germinability under excess water conditions.

Takeda and Fukuyama (1983) evaluated the water sensitivity of 2,212 Asian barley cultivars based on the germination test using a standard and double amount of water in Petri dishes. There were very large varietal differences in water sensitivity, 0-100%, and hulled varieties were generally more sensitive than hull-less ones (Fig. 1).

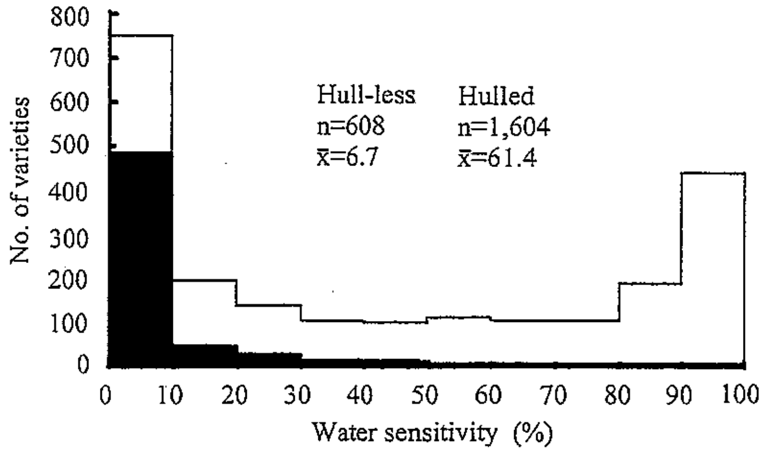

Fig. 1 Varietal differences in water sensitivity in Asian barley cultivars
Solid: Hull-less, Open: Hulled. (After Takeda and Fukuyama, 1983).

Tolerance to pregermination flooding

After a certain period of soaking there was a large variation in germinability, i.e., some of the barley varieties were completely killed and others survived. This type of tolerance is important, especially in East Asia where barley is grown in paddy fields after rice cultivation, because barley fields are often flooded after sowing.

Takeda and Fukuyama (1986) examined the germinability of ca. 3,400 barley accessions after 4 days of soaking at 25℃.

Varietal differences showed a bimodal distribution (Fig. 2). Varieties from the countries west of India were generally sensitive to soaking while the varieties from the countries east of Nepal were tolerant.

Flooding tolerance after germination

Okubo and Takeda (1994) evaluated 3,165 barley varieties for flooding tolerance of the seedlings. Seedlings were grown in a pan up to the second leaf stage and soaked in water at 25℃ for 3-4 weeks, then the vigor of the shoots and roots was scored separately. The varietal differences in the score (0 : sensitive, 10 : tolerant) showed a normal distribution (Fig. 3).

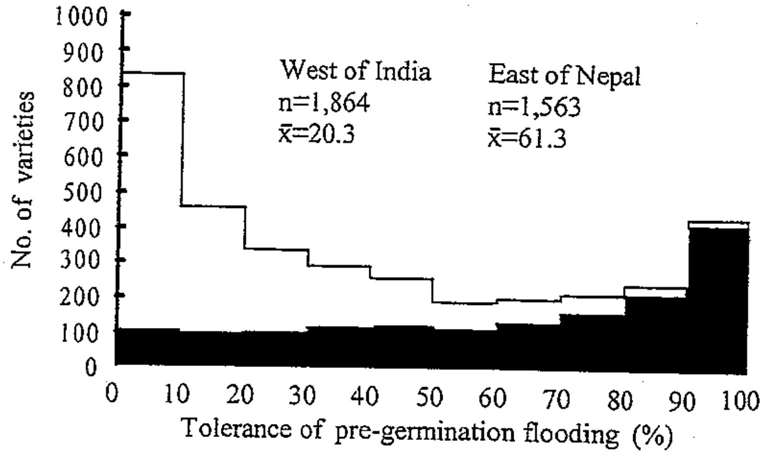

Fig. 2 Varietal differences in tolerance to pre-germination flooding
Open: Varieties from west of India,
Solid: Varieties from east of Nepal.
(After Takeda and Fukuyama, 1987).

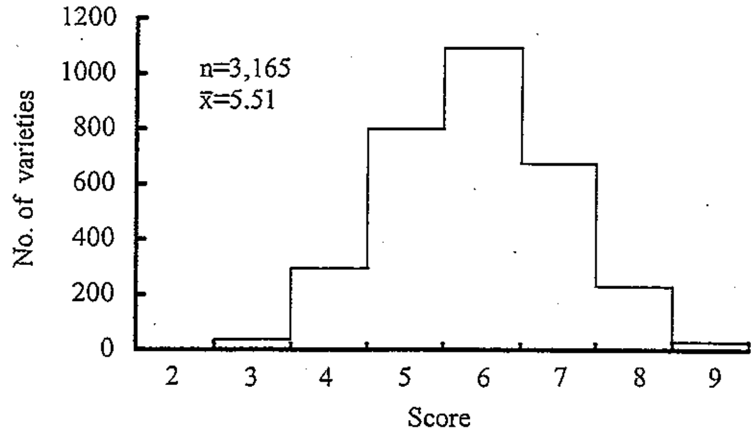

Fig. 3 Varietal differences in the score of flooding tolerance at seedling stage
(After Okubo and Takeda, 1991).

Tolerance to pre-harvest sprouting or seed dormancy

Pre-harvest sprouting which is mainly controlled by seed dormancy is a kind of wet injury.

Takeda (1995) evaluated the dormancy of more than 4,000 barley cultivars. The spikes were harvested at the time of yellow ripeness, immediately dried, hand-threshed and stored at 25℃ for 15 weeks. Germination tests at 25℃ were conducted at 0, 5, 10 and 15 weeks after harvest.

Germination percentage at harvest time showed the largest varietal differences, assuming a typical bimodal patterm, i.e., dormant or non-dormant.

Remarkable geographical differentiation in seed dormancy was disclosed (Fig. 4). Most of the varieties from Ethiopia were non-dormant while most of the varieties from North Africa, Turkey and East Asia were dormant.

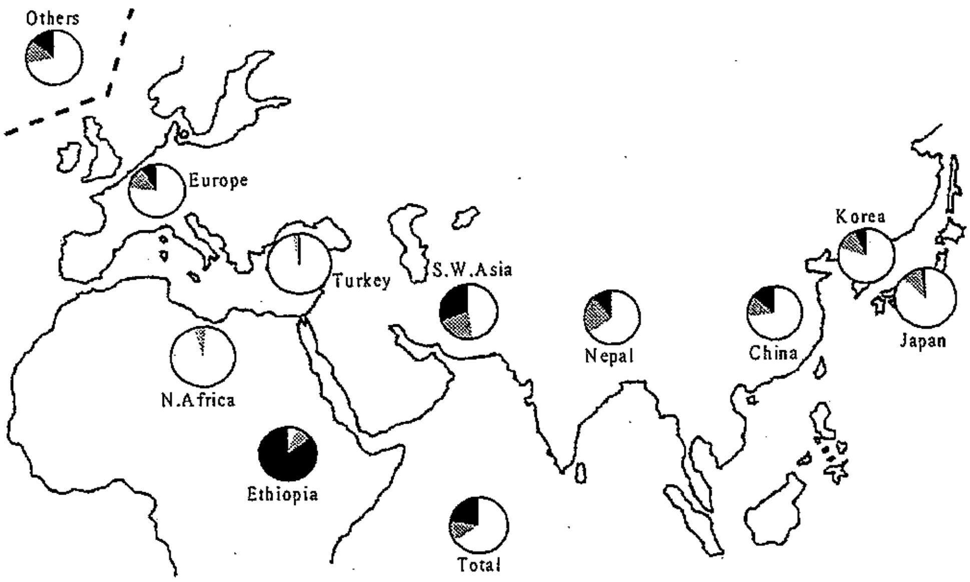

Fig. 4 Varietal differences in seed dormancy (n = 4, 422)
Black: None, Gray: Medium, White: Deep. (After Takeda, 1995).

Deep-seeding tolerance

In the semi-arid areas, the farmers plant the seeds in depth to utilize the soil moisture. Under these conditions, deep seeding tolerance is an important component of drought tolerance..

Takeda and Takahashi (1999) examined the percentage of emergence in a total of 5,082 barley accessions. Deep-seeding tolerance showed a wide range of variation, 0-100% from 12cm depth, and a semi-dwarf "uzu" type was remarkably weak (Fig. 5).

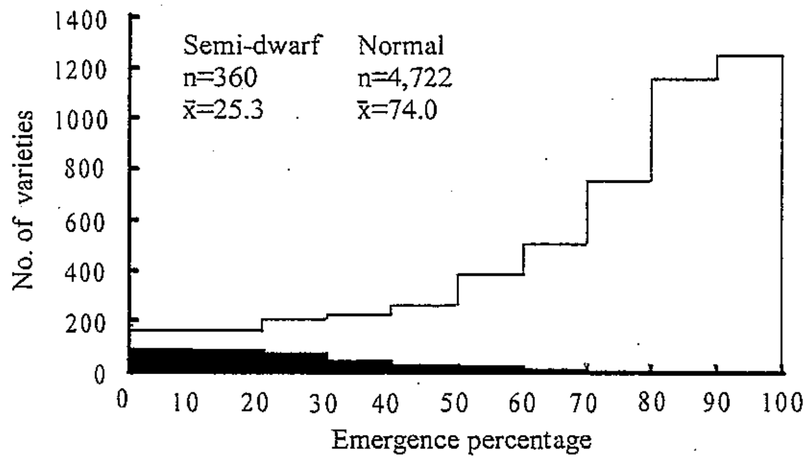

Fig. 5 Varietal differences in emergence percentage from 12 cm seeding depth in semi-dwarf, uzu (solid) and normal (open) cultivars (After Takahashi and Takeda, 1999).

Salt tolerance at germination

Mano et al. (1996) evaluated 6,712 barley accessions for salt tolerance at the time of germination. Varietal differences showed a normal distribution (Fig. 6). There was a close correlation (r=0.789) between the germinability in NaCl solution and in a polyethlene glycol solution with the comparative osmotic pressure, suggesting that salt tolerance at the time of germination was mainly correlated with the osmotic response.

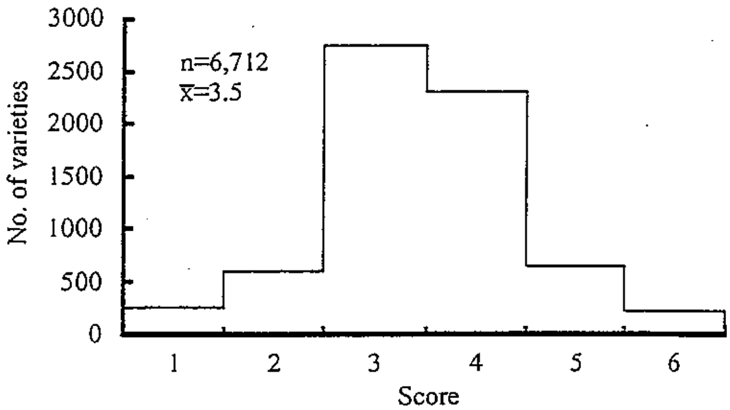

Fig. 6 Varietal differences in the score of salt tolerance at germination (After Mano *et al.*, 1996).

Salt tolerance at seedling stage

Mano and Takeda (1995) evaluated 5,182 barley cultivars for salt tolerance at the seedling stage. Varietal differences showed a normal distribution (Fig. 7). Correlation between salt tolerance at the time of germination and at the seedling stage was independent (r= - 0.061), suggesting that the mechanism of tolerance varies with the stages of growth.

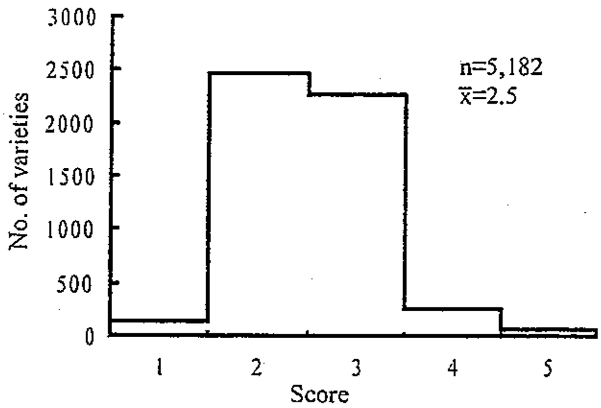

Fig. 7 Varietal differences in the score of salt tolerance at seedling stage (After Mano and Takeda, 1995).

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