Wheat Special Report No. 27

# Breeding for Resistance to Fusarium Head Blight of Wheat in the Mid- to Lower Yangtze River Valley of China

Yang Zhuping, Visiting Scientist

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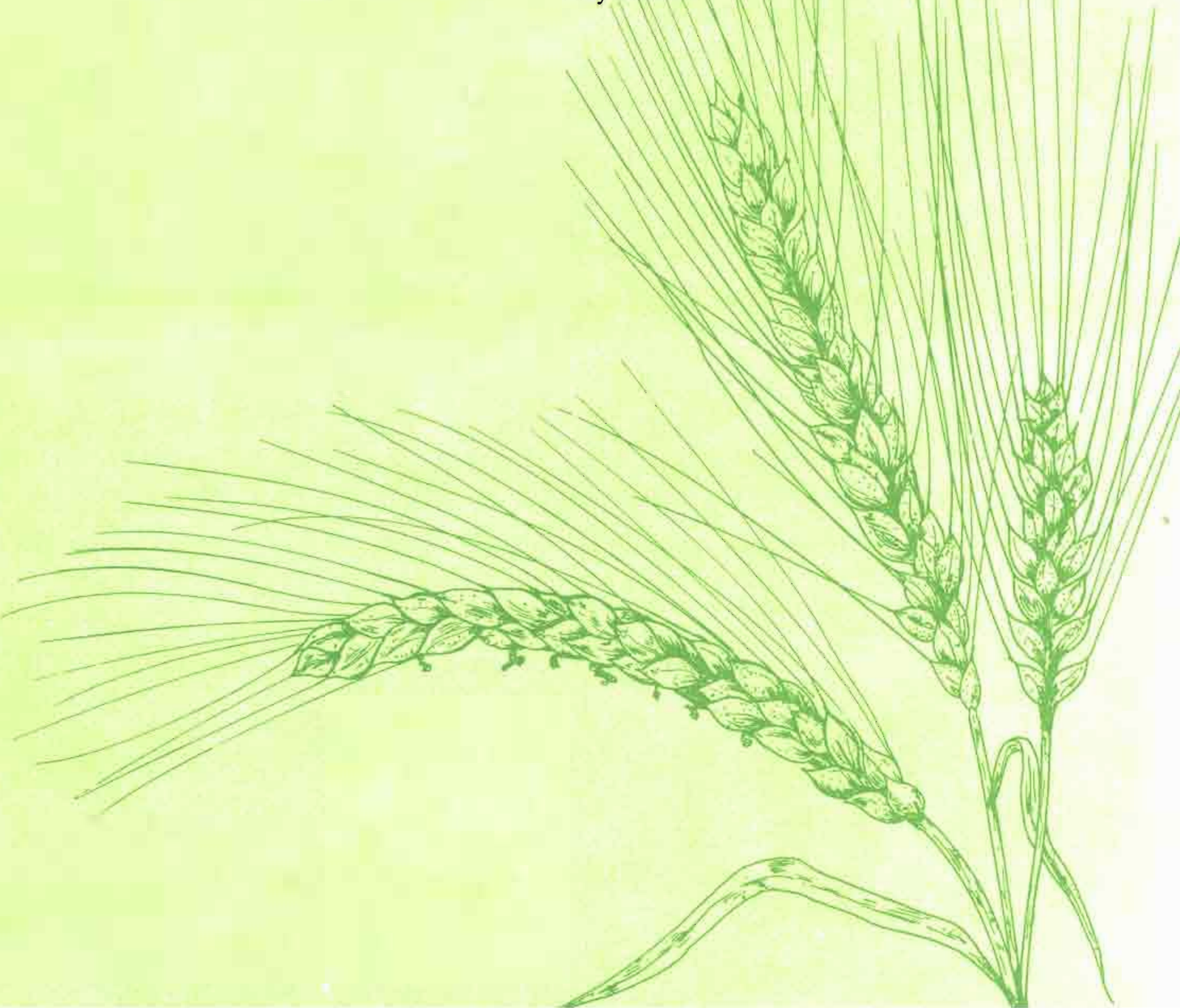

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## Contents

## Preface

Fusarium head blight (FHB) of wheat or scab is an important fungal disease in many areas of the world, especially where humid moist conditions prevail from heading to maturity. It is a particularly troublesome disease in China where more than 6.7 million hectares of wheat are affected--primarily in the mid- to lower Yangtze River Valley.

In this special report, CIMMYT visiting scientist Yang Zhuping provides an overview of the effort in China to breed for FHB resistance. I believe the information will be of interest to those concerned with Chinese wheat research.

An earlier installment in this series (Special Report No. 2: He and Chen 1991) provides an excellent general background about Wheat and Wheat Breeding in China.

**S. Rajaram**
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**Note on Citing this Wheat Special Report**
The information in this wheat special report is shared with the understanding that it is not published in the sense of a refereed journal. Therefore, this report should not be cited in other publications without the specific consent of S. Rajaram, CIMMYT Bread Wheat Program.

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## Introduction

Fusarium head blight or scab (*Fusarium* spp.) of wheat is a destructive fungal disease in both the temperate and semi-tropical wheat-growing regions of the world. These areas include Japan, China, parts of North and South America, and eastern Europe (Li 1982, Wu et al. 1984, Ireta and Gilchrist 1994).

More than 6.7 million hectares in China are affected by FHB (Li 1982). By far the largest area affected is in the mid- to lower Yangtze River Valley where spring wheat is fall-planted. In this region, where FHB has a high frequency and causes severe yield losses (Jin 1983), the climate is warm with sufficient rainfall. The annual average temperature and rainfall range from 15-19 $^{o}$C and 800 to 1,500 mm, respectively. Soft red wheat (*Triticum aestivum*) is widely planted. Wheat varieties are sown in the fall, but are mainly of spring habit (there are some facultative types) with little or no vernalization requirement or photoperiod sensitivity. There is excessive but erratic rainfall during the wheat growing season, particularly in the spring. The average rainfall from the elongation stage to maturity ranges from 270 to 320 mm. There is one rainy day in every 2-2.5 days. In some years, up to 400 mm may fall during this period, which can seriously injure normal wheat growth and development.

Excessive moisture is the major reason for wheat production instability; it also enhances FHB infection. Seven years of serious epidemics and 12 years of moderate epidemics occurred during the 1951-1985 period. In serious epidemic years, FHB incidence was 50-100% and yield was reduced by 10-40%. In moderate epidemic years, the incidence was 20-40% and yield was reduced by 5-15%. More than 1 million tons of wheat can be lost in a serious epidemic. In addition, grains contaminated by fusarium mycotoxins, such as deoxynivalenol and zearalenone, are toxic to domestic animals and humans that consume the infected grain (Wu et al. 1984; Anonymous 1988, 1989). Large-scale human toxicoses (>50,000 people) have been reported in China and India (Anonymous 1988, 1989; Bhat et al. 1989). Wheat varieties with resistance to FHB toxin production and other diseases, high-yield potential, and wide adaptability are needed to improve wheat production in the mid- to lower Yangtze River Valley.

FHB has become a serious problem in China due to at least three factors:

- Susceptible/moderately susceptible high-yielding varieties are planted over large areas;
- Sufficient inoculum is present during the flowering stage;
- Weather (rainy and warm) is favorable for the production and dispersal of the fungus spores.

Since the 1950s in China, numerous studies have been done on the causal organism, screening techniques and evaluation criteria for resistance, screening resistant germplasm, inheritance, and breeding for resistance. This special report highlights some of the significant advances achieved with this research.

## FHB Resistance Types

Resistance to FHB infection consists of primarily two components:

- Component 1--Resistance to initial penetration by the fungus.

• Component 2--Resistance to spread of the pathogen within the plant tissues (Schroeder and Christensen 1963).

Most Chinese researchers agree with this viewpoint and believe that component 2 should be the major emphasis because yield losses are limited even though the fungus is present (Wang et al. 1982, Xu and Fan 1982, Wu et al. 1984). In breeding FHB-resistant wheat genotypes, it is ideal to select wheat genotypes that possess both components.

Recent studies have demonstrated that the secondary metabolites of fusarium affect and are affected by plant cells. Acetylated secondary metabolites are deacetylated by plant enzymes. For example, deoxynivalenol can be produced by wheat and maize cells from 3- or 15-acetydeoxynivalenol produced by the fungus (Miller et al. 1983, Yoshizawa and Morooka 1975). Various studies have shown that some wheat and maize varieties have enzymes that degrade deoxynivalenol *in vivo* (Miller et al. 1983, Miller and Young 1985). So, Miller et al. (1983) and Snijders and Perkowski (1990) proposed a third component of resistance, based on the plant's ability to degrade the phytotoxic mycotoxin, deoxynivalenol. See *in vitro* selection on page 10.

## *Fusarium* spp. in China

FHB in China is caused by a number of *Fusarium* spp. Chinese researchers have identified 19 species from 2,450 isolate samples collected in 21 provinces or cities (**Table 1**). Fourteen species were found from 476 isolate samples in Jiangsu Province (Wang and Miller 1988). Among these, *Fusarium graminearum* was the predominant species, representing 94.5 and 91.6% of total samples, respectively. Since the causal fungi of FHB are facultative, nonspecific parasites, the host range is extensive. Inoculum, which can be seedborne, soilborne, or airborne, is produced on infected crop and weed debris. Dispersal of spores by wind and splashing water leads to infection of the upper sheaths and heads of the wheat plants.

## Virulence

The virulence of 102 isolates of *F. graminearum* collected from 33 counties in Jiangsu Province was determined on nine representative wheat varieties by injecting a spore suspension into a single floret of an excised wheat spike *in vitro* (Wang et al. 1982). Significant differences were found in virulence of isolates and in the resistance response of the wheat varieties, but no pathogenic specificity of the isolates of *F. graminearum* was found. Based on differences in morphology and perithecial production, *F. graminearum* isolates are subdivided into Group 1 and Group 2 (Burgess et al. 1975). Generally, isolates of Group 1 are associated with crown rot, while those of Group 2 cause head blight--although Group 1 can produce identical head blight symptoms to those of Group 2 (Burgess et al. 1987). In general, the most virulent isolate or mixture of several strains is inoculated for FHB resistance screening.

The results of virulence experiments on the types and concentrations of inoculum (*F. graminearum*) showed that there were no significant differences in pathogenicity between ascospores and conidia or between 1 to 2 and 100 spores per 5 μl suspension. Therefore, conidial suspensions containing 100-200 spores were used inoculation purposes.

## Screening Techniques

### Inoculation methods

The following inoculation methods are generally used for screening FHB in China. The level and stability of resistance in wheat varieties can be effectively identified by using them.

**Table 1. The species of wheat fusarium head blight in P.R. China.**

| Species | Distribution 21 provinces of China (%) | In Jiangsu (%) |
|---|---|---|
| *Fusarium graminearum* Schwabe | +(94.5) | +(91.6) |
| *F. culmorum* (W.G. Smith) Sacc. | + | +(0.42) |
| *F. camptoceras* W.& R. | + | +(0.63) |
| *F. moniliforme* Sheld. | + | +(1.47) |
| *F. subglutinans* (W. & R.) Nelson, (Tousson & Marasas) | + | +(0.21) |
| *F. longipes* W. & R. | + | - |
| *F. equiseti* (Corda) Sacc. | + | +(0.21) |
| *F. compactum* Gordon | + | - |
| *F. sambucinum* Fuckel (W. & R.) | + | - |
| *F. graminun* Corda (W. & R.) | + | +(0.21) |
| *F. avenaceum* (Fr.) Sacc. | + | +(1.05) |
| *F. tricinctum* (Corda) Sacc. | + | - |
| *F. acuminatum* Ell. et Ev. | + | - |
| *F. nivale* (Fr.) Ces | + | +(0.21) |
| *F. sporotrichioides* Sherb. | + | +(0.42) |
| *F. chlamydosporum* (W. & R.) | + | - |
| *F. semitectum* Berk.& Rav. | + | +(1.36) |
| *F. oxysporum* Schlecht. emend. Synd. & Hans | + | +(0.21) |
| *F. solani* (Mart.) Appel & Wollenw. | - | +(0.63) |
| Unknown | - | +(1.47) |
| Total no. of isolates | 2450 | 476 |

+ or - indicates species presence or absence.

**Spreading infected grains on the soil surface**--Numerous breeding materials from the F1 to advanced lines are evaluated in preliminary screening nurseries after inoculation by spreading infected wheat grains on the soil surface (Xu and Fan 1982, Lieu et al. 1985). It is necessary to keep the screening nursery sufficiently moist by spraying water during the heading through milk stages. Two inoculations are made at 15 and 5 days before heading so that all materials with different heading dates can receive adequate amounts of *F. graminearum* spores. This method simulates a natural epidemic in the screening nursery. Components 1 and 2 can be effectively evaluated using this inoculation procedure.

**Injection of a conidial suspension into the floret**--Advanced lines showing FHB resistance in the preliminary screening nursery are further evaluated by injecting a conidial suspension into the florets during flowering in the elite screening nursery (Wang et al. 1982). This method is precise and reliable because the inoculum can be applied quantitatively.

Satisfactory results can be obtained in the laboratory by injecting the inoculum into a single floret in the middle of an excised wheat spike, which is placed in a bottle filled with tap water and kept at 20-25$^{o}$C and 95% relative humidity (after 2-3 days reduced to 75%) (Xu et al. 1985). By comparing results of laboratory and field screenings, the influence of environmental factors can be identified and reduced. This allows for more effective evaluation of component 2 resistance.

**Multilocation testing**

Multilocation testing of the better advanced lines for FHB resistance is conducted in different regions where epidemics frequently occur. Since 1987, such testing has been conducted at more than 30 sites in the river valley. Elite advanced lines with high resistance are further evaluated in Fujian Province where FHB occurs naturally each year at relatively high levels. It should be noted that, if disease levels are too high, different levels of FHB resistance will be difficult to distinguish.

**Criteria for evaluating resistance**

**Disease scoring**--Spikes infected with *F. graminearum* are scored using a 1-to-5 scale, based on infection and disease spread as follows:

1) Disease is restricted to the inoculated (initial) spikelet and there are no symptoms on the axis;

2) The axis is infected, but the second spikelet adjacent to inoculated spikelet is not;

3) The axis and second spikelet adjacent to inoculated spikelet is infected, but the spike holding the inoculated spikelet is not wilting;

4) The axis and additional spikelets are infected; the spike holding the inoculated spikelet is wilting, but pathogen moves slowly down the inoculated spikelet;

5) Pathogen moves quickly up and down the axis, and entire spike quickly wilts.

The scores are classified as follows:

| | |
|---|---|
| R = 1.1-2.0 | MS = 3.1-4.0 |
| MR = 2.1-3.0 | S = 4.1-5.0 |

Components 1 and 2 can be effectively evaluated using the above scoring. See pages 13-14 of Ireta and Gilchrist (1994) for other useful scoring scales.

**Infected spikelet rate (%)**--This percentage is calculated as follows:

$$\text{Infected spikelet rate} = \frac{\text{Spikelets infected with } F. \textit{ graminearum}}{\text{Total no. spikelets per spike} \times 0.01}$$

**Infected spike rate (%)**--This percentage is calculated as follows:

Infected spike rate = (Spikes infected with *F. graminearum*/Total no. of spikes tested) x 100

The infected spike rate cannot precisely reflect FHB resistance, but it does represent epidemic severity.

**Germplasm screening**

Parry et al. (1984) showed that English winter wheat varieties differed significantly in their resistance to head blight caused by *F. culmorum*. Based on 15 years of screening for resistance to *F. culmorum*, a study in 1988 did not find resistance in hundreds of *Triticum* spp., 21 *Aegilops* spp., and 11 *Agropyron* spp. However, some lines from CIMMYT showed high levels of FHB resistance (Rajaram 1988).

Since 1974, research institutes in the Yangtze region have screened wheat germplasm from China and abroad for MR or R reactions to FHB (**Table 2**). Although no immune materials were found, responses were significantly different (Lieu et al. 1985, Wang et al. 1982). Some materials with high and stable resistance, such as Wangshuibai and Fanshanmai (old indigenous varieties), Xinzhongchang and Yangangfangzhu (Japanese wheat varieties), Frontana (Brazilian variety), Sumai No. 3 and Ning 7840 (improved Chinese wheat varieties), were identified (**Table 3**). Breeders have found that FHB resistance of these varieties can be easily transferred to their offspring. Some *Aegilops* and *Agropyron* spp. have fairly high FHB resistance (Yang and Wu 1989). The search continues for new FHB resistance sources.

**Table 2. Results of screening germplasm for FHB resistance by research institutes in the mid- to lower Yangtze River Valley, P.R. China.**

| Years | No. of materials tested | MR and R | | Institution |
|---|---|---|---|---|
| | | No. of materials | % | |
| 1974-1982 | 34572 | 1780 | 5.1 | NWSCRG |
| 1978-1883 | 17621 | 385 | 2.1 | SAAS |
| 1975-1985 | 7521 | 451 | 5.9 | JAAS |
| 1976-1983 | 6146 | 482 | 7.8 | ZAAS |
| 1983-1985 | 1733 | 190 | 10.9 | HAAS |

NWSCRG: National Wheat Scab Cooperative Research Group.
SAAS: Shanghai Academy of Agricultural Sciences.
JAAS: Jiangsu Academy of Agricultural Sciences.
ZAAS: Zhejiang Academy of Agricultural Sciences.
HAAS: Hubei Academy of Agricultural Sciences.

**Table 3. Some FHB-resistant germplasm used in Chinese wheat breeding.**

| Name | Pedigree | FHB resistance reaction | Yield (t/ha) |
|---|---|---|---|
| Fanshanmai | | MR | |
| Xinzhongchang | | MR | |
| Wangshuibai | | R | |
| Yangangfangzhu | | R | |
| Frontana | Fronteira/Mentana | R | |
| Sumai No. 1 | Funo/Taiwanmai | R | |
| Sumai No. 2 | Funo/ Taiwanmai | R | |
| Sumai No. 3 | Funo/ Taiwanmai | R | |
| Zheng 7495 | Fusuihuang/Youyimai | MR | |
| Ning 7840 | Aurora/Anhui No.11//Sumai No.3 | HR | 4-5 |
| Ning 8017 | Aurora/Sumai No.3//Yangmai No.2 | MR | 4-6 |
| Ning 8026 | Aurora/Sumai No.3//Yangmai No.2 | MR | 4-6 |
| Ning 8428 | 75-6711/Lovrin//Ning 7840 | MS-MR | |

During a 4-year period, Snijders (1990a) evaluated 258 winter and spring wheats for resistance to head blight after inoculation with *F. culmorum*, and found that genetic variation for resistance is very high. Spring wheats reported to be resistant to head blight caused by *F. graminearum* were also resistant to *F. culmorum*. This resistant germplasm was divided into three gene pools: 1) winter wheats from Eastern Europe, 2) spring wheats from China/Japan, and 3) spring wheats from Brazil. It can be postulated that FHB-resistant germplasm will be found in regions that have epidemics.

## Inheritance of Resistance

Breeding for FHB resistance is hampered by lack of knowledge on the inheritance of resistance. Inheritance studies are scarce and have been limited to resistance to *F. graminearum*. Some reports have shown that resistance is controlled by a few genes (Nakagawa 1955), while others have reported that resistance is inherited quantitatively with low heritability. However, the estimated number of resistance genes is small (< 5 in the entire spring wheat population of China). Individual genes have large effects and the inheritance is mainly additive (Lin et al. 1992, Wu et al. 1984, Chen 1983, Zhang and Pan 1982).

Gu (1983) reported resistance in the F1 tended to resemble that of the resistant parent and the F2 showed a dominance effect for resistance. Xia et al. (1984) showed that the frequency distribution of resistance levels in the F2 had two peaks. The resistance of wheat varieties Wangshuibai and Sumai No. 3 (and its derivative line Ning 7840), which is high and stable, appears to be dominant with good combining ability. The inheritance of resistance seems to be governed by two or three major genes and additional minor genes (Zhou et al. 1987).

The number of major genes varies with varieties. There are three major genes in Wangshuibai, two in Sumai No. 3 and Ning 7840, and one in Yangmai No. 4. The major genes from different varieties may have different effects. The genes in Sumai No. 3 may impart the best resistance.

Using monosomic analysis to study the inheritance of resistance in Sumai No. 3, Yu (1982) showed that at least five pairs of genes, which determine resistance to hyphal spread, were located on chromosomes 1B, 2A, 5A, 6D, and 7D. Also using monosomic analysis, Liao and Yu (1985) reported that five pairs of resistance genes in Wangshuibai were located on chromosomes 4A, 5A, 7A, 7B, and 4D.

Lin et al. (1992) studied inheritance of resistance using a set of diallel crosses among seven spring and winter genotypes that represented different levels of resistance (including Sumai No. 3, Xinzhongchang, and Wangshuibai). The parents, F1s, and F2s were inoculated with the Wangting strain (Jiangsu) of *F. graminearum*. The results showed that inheritance of resistance is governed by the additive-dominance model with additive gene action being the most important factor of resistance. The number of genes governing resistance in this population was estimated to vary from two to four. The general combining ability effects played a major role. Resistance was uniformly transmitted to all offspring; the parents can be described in terms of general combining ability.

Selection of progeny from a cross between parents with high general combining ability for resistance should have successful results. Sumai No. 3 and Xinzhongchang, which have high general combining abilities and good agronomic traits, are recommended for use as resistant parents in breeding programs (Yang and Lin 1992).

**Genotypic correlation between resistance and agronomic traits**
There are reports of genotypic correlations between FHB resistance and agronomic traits. In general, there are positive relationships between resistance and plant height (Nakagawa 1955, Chen 1983, Lin et al. 1992) and negative relationships between resistance and spikelets/cm of ear length (Chen 1983). Prolonged wet periods during flowering are critical to infection. Since wheat is less susceptible prior to and after anthesis, selecting lines with short flowering periods is recommended. Additionally, lines with low choline and glycinebetaine may be correlated with resistance because infection begins almost exclusively on the extruded anthers and anther tissue, which is high in choline and glycinebetaine (which greatly stimulate the growth of *F. graminearum*).

## Breeding Strategies

He and Chen (1991) provide a good general overview of Chinese wheat breeding. Regarding FHB, studies on inheritance of resistance show a great potential for breeders to develop resistant varieties. There is an analogy with quantitative resistance in other host-pathogen relationships. For example, resistance to *Septoria tritici* in spring and winter wheat varieties is controlled by a small number of genes (usually 2), with mainly additive effects (Danon and Eyal 1990). The partial resistance to wheat leaf rust (*Puccinia recondita* f.sp. *tritici*) in several spring wheat genotypes is based on only a few genes (< 3), some of which have relatively large effects (Broers and Jacobs 1989). The results of these studies indicate that quantitative resistance can be based on only a few genes. Therefore, transmission of quantitative resistance from unadapted germplasm to high yielding varieties should be possible with relatively little effort.

An important question in many breeding programs is: in which generation should selection take place? Snijders (1990b) concluded that two resistant parents, SVP75059-28 and SVP72017-17-5-10, differed from a susceptible parent, SVP72005-20-3-1, by having four and five genes, respectively. Lin et al. (1992) found Sumai No. 3 (2 genes) and Wangshuibai (3 genes) differed in 1 major gene and had the other 2 genes in common. This means that the fixed resistance from the selected F3 lines may differ from a common susceptible wheat genotype by as much as 2 or 3 genes. Thus, in a practical breeding program, it is better to delay selection until the F3 or F4; by then homozygotes have formed in an increased delay selection until the F3 or F4; by then homozygotes have formed in an increased proportion of the segregates. However, selection will be successful only if there is uniform and adequate disease pressure in the nursery.

### Intervarietal crosses

At the Jiangsu Academy of Agricultural Sciences, more than 43 parents with different resistance levels have been used to make 1,758 crosses. Of these, more than 80% were composite crosses. Sumai No. 3 has been used extensively as the FHB-resistant parent in Chinese wheat breeding and significant advances have been achieved (Wu et al. 1984; Xia et al. 1984; Zhou et al. 1984, 1987; Yang and Wu 1989). Sumai No. 3 was introduced from Jiangsu Province during 1975-1985 to 60 research institutes in 19 provinces. Twenty-six research institutes have made 5,000 crosses involving Sumai No. 3, resulting in 120 varieties or lines with MR or R reactions to FHB. Some of these have become outstanding commercial varieties. These achievements indicate that the resistance of Sumai No. 3 can be easily transferred as hypothesized earlier.

For many years, commercial wheat varieties or elite lines (**Table 4**) with higher FHB resistance and better agronomic traits were derived from Sumai No. 3 through single or composite crossing. This involved multiparental sequential crossing and continuous single-plant selection by artificial inoculation. This means it is possible to obtain a high level of FHB resistance and simultaneous high-yield potential through intervarietal crossing.

**Table 4. Pedigrees of some varieties or lines released in the mid- to lower Yangtze River Valley with good levels of resistance to FHB.**

| Variety or line | Pedigree | Resistance reaction | Province |
|---|---|---|---|
| E Yin No. 1 | Lovrin 10/761//Sumai No. 3 | MR | Hubei |
| Xiang 10 | Youyimai/Sumai No. 3 | R | Hunan |
| Xiang 11 | Sumai No.3/Dugan 1042 | MR | Hunan |
| Yangmai No. 4 | Nanda 2419/Triumph//Funo | MR | Jiangsu |
| Yangmai No. 5 | Yangmai No.4/St 1472//506 | MR-MS | Jiangsu |
| Su 8113 | A-Zou 3/Sumai No. 3//098 | MR | Jiangsu |
| Ning 7840 | Aurora/Anhui 11//Sumai No. 3 | R | Jiangsu |
| Ning 8675 | Ning 8201/4/263/Fanxiu No. 5 //Ningmai No.4/3/Ning 7840/ Yangmai No. 3 | - MR | Jiangsu |
| Ning 8176 | Ning 263/Fanxin No. 5// Ningmai No.4/3/Ning 7840/ Yangmai No. 3 | MR | Jiangsu |
| Ning 8343 | Yangmai No. 3/3/Ningmai No.3 /Sumai No. 1//Sumai No.3/ Aurora | MR | Jiangsu |
| Jinhui 6071 | Potam S 70/Sumai No. 3// Fu 32-3 | MR | Zhejiang |

R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.

In an attempt to introduce a new gene pool to China, numerous lines containing CIMMYT germplasm have been introduced into China since 1967. In general, these varieties have high-yield potential and good rust resistance for the Yangtze River Valley region, but they are highly susceptible to FHB. Some crosses between Chinese and CIMMYT lines have resulted in improved varieties/elite lines that have higher resistance to rust and FHB and better agronomic traits. Some of this material has been selected and released in the Yangtze River Valley. These include Xuzhou 21 (Pulong 3665/Up 301) and Ning 8675 (Ningmai No.4/Olesen//Alondra'S'/Yangmai No.3/3/Ning 8180).

**Recurrent selection**
It is difficult to attain higher resistance levels combined with high yield potential through simple intervarietal crossing (Wu et al. 1984). New breeding methods for FHB resistance were suggested by various workers in the 1980s:

- Zhou et al. (1987) suggested using the multiple-parent crossing method and giving more attention to evaluating and selecting progeny.

- In 1985, CIMMYT began utilizing FHB resistance in the Chinese gene pool by initiating a shuttle breeding program between CIMMYT and Chinese research institutes in the Yangtze River Valley (Rajaram 1988). This involved crossing CIMMYT germplasm with Yangtze varieties and making selections at alternate Chinese and Mexican locations.

- Wu et al. (1984) utilized recurrent selection in a gene pool using a dominant male-sterile gene, $MS_2$.

The work of Wu et al. (1984) involved transferring the $MS_2$ gene, through backcrossing, into five high-yielding wheat varieties, including Yangmai No. 4, Yangmai No. 5, and Ningmai No. 6. These parents with the $MS_2$ gene were then crossed with 15 parents having high FHB resistance, such as Sumai No. 3, Zhen 7495, Xinzhongchang, Wangshuibai. The F1s from each cross were intercrossed with each other and seeds from male-sterile plants were mixed to develop the base population. In this gene pool, elite male-sterile plants with high resistance and better agronomic traits were selected and used as intermating parents in the following cycle. Major and minor resistance genes carried by various resistant parents from different regions were recombined, accumulated, and transferred into high-yielding backgrounds (Yang and Wu 1988).

Yang (1992) conducted four cycles of recurrent selection, using phenotypic mass selection for sterile plants and progeny testing selection for fertile plants, to improve FHB resistance in the gene pool. The number of spikelets infected with *F. graminearum* was reduced significantly and frequencies of FHB-resistant plants were increased. The largest genetic advance was obtained in cycle 1--suggesting that selection acted on the major genes--and on minor genes in cycles 2 through 4. Some fertile semidwarf plants with higher levels of resistance were selected from the improved population (Yang and Wu 1992a,b).

In 1993, the Shanghai Academy of Agricultural Sciences used recurrent selection to develop Lunhun 642, a new high-yielding wheat variety with higher FHB resistance and good baking quality. It can be postulated that new high-yielding varieties with higher levels of FHB resistance can be developed by integrating recurrent selection and conventional breeding methods.

**Transferring alien resistant genes to wheat**
Some *Aegilops* and *Agropyron* spp. have fairly high FHB resistance. Wide crosses can be made between *T. aestivum* and *Aegilops* spp. or between *T. aestivum* and *Agropyron* spp. to

**Transferring alien resistant genes to wheat**
Some *Aegilops* and *Agropyron* spp. have fairly high FHB resistance. Wide crosses can be made between *T. aestivum* and *Aegilops* spp. or between *T. aestivum* and *Agropyron* spp. to introgress this resistance. At the Shanghai Academy of Agricultural Sciences, resulting F1 plants from these wide crosses show high levels of FHB resistance in the screening nursery. Backcrossing the F1 hybrids *T. aestivum* is the next step.

***In vitro* selection**
As mentioned earlier, a third component of resistance has been proposed based on a plant's ability to degrade deoxynivalenol (DON). DON is a pathogen-produced, nonhost-specific toxin that causes physiological changes in infected plant tissue. It may play a role in pathogenesis and pathogen aggressiveness. It is possible that one of the resistance mechanisms is directed at neutralizing DON. If so, plants with low levels of DON should have higher levels of FHB resistance. This phenomenon could facilitate screening for resistance among populations of whole plants, cells, pollen, and protoplasm. Selection for appropriate resistance mechanisms could prevent or retard production of DON in the plant tissue.

At the Shanghai Academy of Agricultural Sciences and Jiangsu Academy of Agricultural Sciences, DON studies were conducted using high-yielding wheat varieties or hybrids between resistant parents and high-yielding genotypes or between *T. aestivum* and its wild relatives. Anthers and immature panicles of these various materials were cultured on Murashige and Skoog media (Murashige and Skoog 1962). Calli were transferred onto media containing different levels of DON so that the calli could be screened for tolerance to DON concentration. Regenerated plants (R1) were evaluated for FHB resistance in the screening nursery. Preliminary results show that the regenerated plants have higher FHB resistance.

## Future Emphasis

Future FHB research in China should emphasize the following:

- Continuing the search for new resistance sources.

- Conducting genetic studies to explore variability in the wheat populations originating from eastern Europe, China, Japan, and Brazil.

- Accumulating resistance genes of known diversity.

- Transferring resistance genes from *Aegilops* and *Agropyron* spp. into *Triticum aestivum.*

- Exploring novel approaches that may contribute to increased levels of resistance.

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