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# Variation in *Fusarium* head blight susceptibility of international and Austrian wheat breeding material[1]

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(With 3 Figures)


## Summary

International and Austrian *Triticum aestivum* L. and *Triticum durum* Desf. genotypes were investigated on their head blight sensitivity after artificial inoculation with one *Fusarium culmorum* and two *Fusarium graminearum* inocula. The spread of the disease was evaluated four to five times. The area under the disease progressing curve (AUDPC) was calculated and standardized (SAUDPC). Determination of relative ear weight and relative grain yield compared to uninoculated controls were carried out. The analyses of the data of these field parameters revealed the presence of significant quantitative differences in head blight susceptibility among the investigated genotypes (means of the SAUDPC of the varieties ranging from 0.10 (high sensitivity) up to 0.74 (low sensitivity) with LSD 5 % = 0.06). All *Triticum durum* genotypes were very susceptible. Significant interactions occurred between genotypes and isolates. The correlation between the visual evaluation data at the 14th day after inoculation and SAUDPC was −0.95. Highly significant correlations were also detected between the data for SAUDPC and relative yield (r = 0.75) and between the data of relative ear weight and relative yield (r = 0.91) (for all r: $P < 0.1$ %). Significant correlations were found between the field data of the individual inocula.


Key-words: *Fusarium*, head blight, wheat, resistance breeding.


## Zusammenfassung

Ein internationales (25 Prüfglieder) und ein österreichisches (47 Prüfglieder) Sortiment von Winterweizen- (*Triticum aestivum* L.) und Durumweizen- (*Triticum durum* Desf.) Genotypen wurden nach künstlicher Inokulation mit einem *Fusarium culmorum* und zwei *Fusarium graminearum* Inokula auf Toleranz gegen Ährenfusariose geprüft. Die Ausbreitung der Krankheit wurde vier- bis fünfmal bonitiert und die Fläche unter der krankheitsverlaufenden Kurve (AUDPC) berechnet und standardisiert (SAUDPC). Neben diesen Parametern


[1] This project has been financed by the Ministry of Agriculture and Forestry, Austria (Forschungsprojekt Nr. L 687/91).

zur Erfassung der Fusarienresistenz ermittelte man durch den Vergleich mit den unbehandelten Kontrollen das relative Ährengewicht (REW) und den relativen Kornertrag (RY) aller Prüfglieder. Die Analyse der Daten dieser Merkmale zeigte signifikante quantitative Differenzen in der Anfälligkeit der Weizengenotypen auf. Die SAUDPC variierte von 0.10 (hochanfällig) bis 0.74 (wenig anfällig), bei einer Grenzdifferenz von $P<5\% = 0.06$. Alle Durumweizen-Genotypen waren sehr anfällig. Zwischen den Genotypen und den verwendeten Isolaten konnten signifikante Wechselwirkungen gefunden werden. Die signifikanten Korrelationen zwischen den visuellen Bonituren am 14. Tag nach der Inokulation und den Flächen der krankheitsverlaufenden Kurve betrugen im Durchschnitt $-0.95$. Zwischen den Daten dieser Kurven (SAUDPC) und den relativen Kornerträgen (RY) konnten signifikante Korrelationen gefunden werden ($r=0.75$); das galt ebenfalls für die Beziehungen zwischen den relativen Ährengewichten (REW) und den relativen Kornerträgen (RY), $r=0.91$. Auch zwischen den Daten aus unterschiedlichen Inokulum-Behandlungen waren hohe Korrelationen feststellbar.

Schlüsselworte: *Fusarium*, Ährenfusariose, Weizen, Resistenzzüchtung.

## 1. Introduction

An increase in the incidence of *Fusarium* head blight (scab) on wheat has been observed during the last years in Austria. One of the major reasons is the increasing part of wheat cultivation in the crop rotation, combined with cropping of maize and intensive nitrogen application (Zwatz 1987). Nine different *Fusarium species* have been isolated from wheat in Austria: *F. culmorum, F. avenaceum, F. graminearum, F. poae, F. equiseti, F. sambucinum, Gerlachia nivalis, F. oxysporum* and *F. solanaceum* (Adler et al. 1990, Zwatz 1987). The most important pathogens of head blight of wheat are *Fusarium graminearum* (Adler et al. 1990) and *Fusarium culmorum* (Zwatz 1987).

Infestation of the ear has several consequences: 1. yield reduction, 2. starch, proteins and cell walls of infected grains are destroyed causing reduction of baking quality, 3. infestation of the embryo leading to reduction of seed quality and 4. production of mycotoxins (Zwatz 1987, Miedaner and Walther 1987). Several *Fusarium* spp. produce mycotoxins which have toxic effects on humans and domestic animals. *Fusarium culmorum* and *Fusarium graminearum* are the main producers of deoxynivalenol (DON, vomitoxin) on wheat (Adler et al. 1990, Miller and Greenhalgh 1988). DON belongs to the class of the trichothecenes B. Biochemically, trichothecenes, including DON, are inhibitors of protein and DNA synthesis. DON affects the immune system of animals (World Health Organization 1990). Decreased feed intake and weight gain, vomiting and feed refusal of domestic animals due to DON contamination of the fodder have been reported. It has been suggested that trichothecenes promote human esophageal carcinogenesis (Luo et al. 1990). *Fusarium culmorum* and *Fusarium graminearum* also produce zearalenon which has an oestrogenic mode of action on animals. The presence of *Fusarium* toxins in naturally contaminated wheat in Austria has been demonstrated (Adler et al. 1990).

At present the possibilities for chemical control of head blight are limited, because an effective fungicide is not available. The above mentioned *Fusarium* spp. are polyphageous and attack wheat as well as other important crops (Zwatz 1987). Head blight and the production of mycotoxins can possibly be controlled by cultivation of resistant wheat varieties. A wide range of resistance among wheat genotypes has been observed (Mielke 1988, Saur 1991, Snijders 1990a, Zwatz 1987, 1988). Although highly resistant varieties such as "Nobeokabozu"

(Japan), "Sumey-3" (China) and "Frontana" (Brazil) have been described (Teich 1989, Zhong and Miller 1987, Mesterhazy 1989), complete resistance was not found (Naito et al. 1984, Mielke 1988). Several mechanisms for genetic resistance have been reported (Teich 1989). A cultivar may be resistant to initial infection, to hyphal spread and/or to the mycotoxins. The number of genes governing resistance varies from 2 to 3 (3 dominant genes in cultivar "Shinchunaga": Nakagawa 1955; 2 to 3 genes in cultivar "Sumey-3": Zhou et al. 1987) up to 6 (in 10 SVP winter wheat cultivars: Snijders 1990 b) and more (polygenic; Gocho 1985, Gu 1983). Several reports demonstrated that resistant varieties can be used successfully in breeding programmes to improve head blight resistance (Mesterhazy 1987, 1989, Tomasovic 1989, Zhou et al. 1987).

Based on the data described above, it was decided to start a *Fusarium* resistance breeding programme in cooperation with Austrian breeders to improve the head blight resistance of their breeding material. In this article the first results are presented. Austrian and international *Triticum aestivum* and *Triticum durum* breeding lines were tested for head blight resistance after artificial inoculation with Austrian *Fusarium* isolates.

## 2. Material and Methods

### 2.1 Wheat breeding material

In 1990 research institutes from five European countries (Hungary, The Netherlands, France, Germany and Austria) formed a winter wheat nursery of 25 *Triticum aestivum* genotypes (five genotypes per country) which were tested in each country. In Austria this material was sown in 10 $m^2$ plots at the experimental station in Groß-Enzersdorf near Vienna.

For the evaluation of the level of resistance of the national breeding material, 40 Austrian wheat breeding genotypes (23 winter *Triticum aestivum* and 17 *Triticum durum*) as well as seven control varieties (commercial Austrian varieties) were investigated. They were cultivated in 10 to 15 $m^2$ plots in Probstdorf near Vienna.

All data presented originate from field trials in 1991.

### 2.2 Production of single spore isolates

*Fusarium* isolates were obtained as described (Nelson et al. 1986) from visibly infected wheat kernels harvested in Austria in 1990. Single spore isolates were obtained as follows: sterile water drops were put on a sterile cover glass. Dilution of a *Fusarium* suspension was performed by dipping the point of a sterile needle in a droplet containing *Fusarium* suspension and transferring part of this suspension to the next sterile water droplet. This procedure was repeated until the last drop contained one macroconidium as controlled with a microscope. All drops but the last one were disinfected with ethanol (95 %) and the cover glass was incubated upside down on potato dextrose agar (20 gr/l) at 25 °C. The isolates were identified according to Nelson et al. (1986). The identity of the isolates was confirmed by Dr. Mesterhazy (Cereal Research Institute, Szeged, Hungary).

### 2.3 Production of inoculum

The required amount of inoculum for the experiments was prepared with the bubble breeding method (Mesterhazy 1977). A liquid modified Czapek-Dox medium (up to 10 l) was inoculated with the desired *Fusarium* isolate and continuously aerated with sterile air. After one week at room temperature, the suspension was homogenized with a blender (10 s) and was ready for use.

## 2.4 Determination of the number of colony forming units/ml

Inocula were diluted (1 : 10 to 1 : 100 000) and 1 ml was plated out in Petri-dishes (diameter 15 cm) filled with Nash-Snyder-PCNB medium (NELSON et al. 1986) in three replications. After three days at 25 °C the colony forming units were counted.

## 2.5 The Petri-dish test

The Petri-dish test (MESTERHAZY 1978, 1984) was carried out to 1) find out whether the inocula used in the field tests are pathogenic and 2) determine the virulences of these inocula. Filter paper was laid out in Petri-dishes and 8 ml of inoculum was added. Twenty five seeds per wheat genotype were placed with their embryo upwards on the paper. The dishes were incubated in the dark at 25 °C. On the 2nd day after inoculation the number of germinated kernels was counted, and this number was taken as the control (100 %). From the 3rd up to the 6th day the number of healthy seedlings was daily counted and expressed as fraction of the control.

Data processing was carried out as follows. The percentage of healthy seedlings was plotted against the days after inoculation. The data were connected with straight lines and the area (X) under the curve from the 2nd day to the 6th day was calculated and standardized according to formula (1).

$$SA = \frac{X\,\% \times day - 50\,\% \times day}{400\,\% \times day - 50\,\% \times day} \qquad (1)$$

SA = standardized area,
X = area under the curve (in % × day),
50 = area under the curve if all seedlings were diseased at the 3th day after inoculation (in % × day),
400 = area under the curve when all seedlings would remain healthy (in % × day).

The SA varies from 0 to 1: a low SA indicates a high virulence of the inoculum.

## 2.6 Properties of the inocula used in the field experiments

Inocula were prepared from three different single spore isolates (see table 1): *Fusarium graminearum* nr. 91031 and 91047 (isolated from *Triticum durum* kernels) and *Fusarium culmorum* nr. 91401 (from *Triticum aestivum*). The number of colony forming units/ml was determined as described above. An assortment of 30 different Austrian commercial wheat varieties was used to determine the virulence of the inocula applicated in the field tests. This was carried out with the Petri-dish test as described before. The mean of the SA values for the 30 varieties was taken as a measure for the virulence of an inoculum. The virulence of the inocula was tested before and after the field inoculation period and proved to remain constant during this period.

Table 1

*Characteristics of the inocula of Fusarium culmorum and Fusarium graminearum, described by source, colony forming units and virulence*

| Isolate number | Inoculum number | *Fusarium species* | Source | Colony forming units/ml | Virulence before and after field inoculation | |
|---|---|---|---|---|---|---|
| 91031 | 1 | *F. gram.* | *T. durum* | $54 \times 10^4$ | 0.61 | 0.65 |
| 91047 | 2 | *F. gram.* | *T. durum* | $69 \times 10^4$ | 0.06 | 0.08 |
| 91401 | 3 | *F. culm.* | *T. aestivum* | $138 \times 10^4$ | 0.66 | 0.67 |

## 2.7 Field inoculation

Bunches of 25 ears were inoculated at anthesis by spraying 20 ml of a *Fusarium* suspension directly on the heads. The ears were covered with a plastic bag for 24 hours (MESTERHAZY 1978). Each inoculum was sprayed on a separate bouquet. Control bunches were treated in the same way, but with distilled water. Three replications were used within the same plot.

Visual evaluation started on the 10th day after inoculation and was repeated every 4th day until ripening of the wheat makes visual evaluation of the disease impossible (four times for the international wheat nursery and five times for the Austrian breeders material). The percentage of bleached spikelets in the inoculated bunch was estimated according to the following scale: 0 = no symptoms; 4 = 100 % diseased; between 0 and 1 disease symptoms were estimated at one decimal exactly, between 1 and 4 at half a unit).

The bouquets were harvested after ripening and ten representative ears per bunch were used for further analysis. The length, ear weight and yield of the ten ears as a whole was determined. The Austrian wheat breeding material was threshed with a single ear thresher, the international wheat nursery material by hand. In the latter material the number of kernels were counted.

The data of visual scoring of the disease development were processed as follows. The data were plotted against the day after inoculation and were fitted to a logistic curve according to equation (2);

$$y = \frac{a}{(1 + b \times e^{-c \times x})} \tag{2}$$

For linearisation of the data, equation (3) was used;

$$\ln(a/(1-y)) = \ln c + b \times x \tag{3}$$

The area under the disease progressing curve (AUDPC) was calculated by integration of equation (2) (from day 0 (inoculation) to the last day of visual evaluation). The standardised AUDPC (SAUDPC) was then calculated with equation (4);

$$SAUDPC = 1 - AUDPC/AUDPC_{max} \tag{4}$$

where $AUDPC_{max}$ is the maximum possible area obtained when on the 10th day after inoculation all spikelets in the bunch would be diseased.

The data for the SAUDPC range from 0 to 1: a low SAUDPC indicates a low resistance of the wheat genotype or a highly virulent inoculum.

In order to compare different wheat genotypes, relative ear weight (REW), relative ear length (REL) and relative kernel yield (RY) of ten ears were calculated (relative to the characters of the non inoculated control bundles which are all 1.00). In addition relative number of kernels (RKN) and relative 1000-kernel-weight (RTKW) were calculated for the material in the international nursery.

## 2.8 Statistical analysis

The model used in the analyses of variance of the field data is summarized in equation (5):

$$Y_{ijk} = \mu + G_i + I_j + R_k : G_i + (G \times I)_{ij} + e_{ijk} \tag{5}$$

in which G stands for genotype, I for inoculum and R for replication. R was considered a random effect, G and I fixed. Analyses of variance were carried out with Plabstat Version 2C (UTZ 1987).

The following symbols indicating significance levels were used: ***, $P < 0.1$ %; **, $P < 1$ %; *, $P < 5$ %; ns, not significant; +, $P < 10$ %.

*List of Abbreviations*

| | |
|---|---|
| A: | Austria |
| AUDPC: | area under the disease progressing curve |
| DON: | deoxynivalenol |
| F: | France |
| G: | genotype |
| Ge: | Germany |
| H: | Hungary |
| I: | isolate |
| N: | The Netherlands |
| PCNB: | pentachloronitrobenzene |
| R: | replication |
| REL: | relative ear length |
| REW: | relative ear weight |
| RKN: | relative kernel number |
| RTKW: | relative 1000-kernel-weight |
| RY: | relative kernel yield |
| SA: | standardized area |
| SAUDPC: | standardized area under the disease progressing curve |

## 3. Results

### 3.1 International wheat nursery

The spread of head blight disease in artificially inoculated bunches is illustrated in fig. 1 with two examples of winter wheat genotypes with different resistance. For the genotype Bence the percentage of diseased spikelets for inoculum 1 at the 14th day after inoculation was about 5 % (fig. 1 A) while it was 50 % in the case of the variety SL 8/80-28 (fig. 1 B). All three inocula were pathogenic and different in their virulence as shown by their virulence order 2 > 3 > 1 for both genotypes.

The infestation score (SAUDPC) of the field trials with the three inocula and the results of the analysis of variance are illustrated in table 2. Significant differences were detected between the wheat genotypes. The best genotypes were Bence, Arina and 81 F 3 79. The investigated Austrian genotypes showed moderate (NR 172/90) to high sensitivity (SL 8/80-28). A significant interaction occurred between genotypes and isolates. This effect was however small in comparison

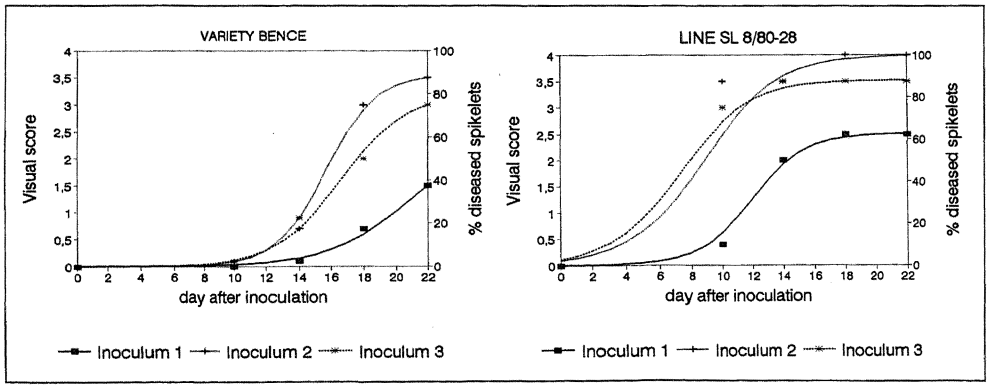


*Fig. 1: Spread of head blight symptoms in the genotype Bence (fig. 1A) and the genotype SL8/80-28 (fig. 1B) after artificial inoculation with three isolates*

Table 2

*Data and analysis of variance table for SAUDPC data of the international wheat nursery. The genotypes were sorted in descending order of resistance. The country of origin of the genotype is indicated between brackets. [1]) mean of three replications; [2]) overall mean of three replications and three inocula*

| Genotype | SAUDPC Inoculum 1[1]) | 2[1]) | 3[1]) | Mean[2]) |
|---|---|---|---|---|
| BENCE (H) | 0.90 | 0.66 | 0.68 | 0.75 |
| ARINA (N) | 0.79 | 0.61 | 0.69 | 0.70 |
| 81 F3 79 (F) | 0.88 | 0.56 | 0.67 | 0.70 |
| 82 F3 28 (F) | 0.88 | 0.52 | 0.67 | 0.69 |
| SVP 75059-28 (N) | 0.83 | 0.55 | 0.66 | 0.68 |
| SVP 72017-17 (N) | 0.81 | 0.52 | 0.58 | 0.64 |
| 85-92 (H) | 0.76 | 0.51 | 0.61 | 0.62 |
| 204/81/03 (Ge) | 0.71 | 0.59 | 0.57 | 0.62 |
| 25/83/02 (Ge) | 0.74 | 0.44 | 0.65 | 0.61 |
| SVP 72005-20 (N) | 0.77 | 0.52 | 0.54 | 0.61 |
| NR 172/90 (A) | 0.75 | 0.50 | 0.56 | 0.60 |
| SGV/GT-Pdj*Ohr (H) | 0.73 | 0.48 | 0.55 | 0.59 |
| P4371.88 (A) | 0.74 | 0.41 | 0.57 | 0.58 |
| SZÖKE (H) | 0.73 | 0.48 | 0.50 | 0.57 |
| COPAIN (F) | 0.76 | 0.41 | 0.54 | 0.57 |
| 47/83/02 (Ge) | 0.72 | 0.43 | 0.53 | 0.56 |
| RC 103 (F) | 0.73 | 0.41 | 0.48 | 0.54 |
| 163/81/01 (Ge) | 0.76 | 0.34 | 0.44 | 0.51 |
| P2119.89 (A) | 0.75 | 0.37 | 0.36 | 0.49 |
| SL 34/81-21 (A) | 0.72 | 0.34 | 0.35 | 0.47 |
| 77/82/01 (Ge) | 0.68 | 0.35 | 0.35 | 0.46 |
| SVP 75059-32 (N) | 0.58 | 0.28 | 0.41 | 0.42 |
| ZOMBOR (H) | 0.50 | 0.29 | 0.35 | 0.38 |
| RESCLER (F) | 0.55 | 0.24 | 0.28 | 0.36 |
| SL 8/80-28 (A) | 0.60 | 0.15 | 0.20 | 0.32 |
| Mean | 0.73 | 0.44 | 0.51 | 0.56 |

Analysis of Variance Table

| Source | DF | SS | MS | F | LSD 5 | DF-DN |
|---|---|---|---|---|---|---|
| G | 24 | 2.72 | 0.113 | 25.05** | 0.06 | 50 |
| I | 2 | 3.56 | 1.789 | 454.47** | 0.02 | 100 |
| R:G | 50 | 0.23 | 0.005 | 1.16ns | 0.10 | 100 |
| I*G | 48 | 0.38 | 0.008 | 2.01** | 0.10 | 100 |
| REST | 100 | 0.39 | 0.004 | | | |
| TOTAL | 224 | 7.27 | | | | |

with the effects of genotype and isolate. The field virulences of the inocula were significantly different ($LSD_5 = 0.02$) and was the highest for inoculum 2, the lowest for inoculum 1.

A summary of the results as well as of the analysis of variance of the other field parameters are presented in table 3. Significant differences between wheat genotypes and between inocula were found for all parameters tested except for relative ear length (results not shown). This parameter was apparently not influenced by the disease. Significant differences between replications within the genotypes for the REW, RY, RKN and REL (result not shown) were detected. Significant interactions between genotype and isolate occurred for the relative values of kernel yield, kernel number and 1000 kernel weight, but the effect is small in each case.

Table 3

*Summary of the data of the field parameters and their analysis of variance for the international wheat nursery (1): n= 75)*

| Inoculum | REW 1 | REW 2 | REW 3 | RY 1 | RY 2 | RY 3 | RKN 1 | RKN 2 | RKN 3 | RTKW 1 | RTKW 2 | RTKW 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum[1]) | 1.02 | 0.98 | 1.02 | 1.10 | 0.61 | 0.86 | 1.12 | 1.02 | 1.12 | 1.10 | 0.92 | 0.89 |
| Minimum[1]) | 0.46 | 0.32 | 0.33 | 0.27 | 0.13 | 0.16 | 0.46 | 0.21 | 0.45 | 0.41 | 0.22 | 0.25 |
| Mean[1]) | 0.77 | 0.58 | 0.60 | 0.66 | 0.37 | 0.43 | 0.88 | 0.69 | 0.78 | 0.76 | 0.56 | 0.56 |

| Source | DF | MS | F | MS | F | MS | F | MS | F |
|---|---|---|---|---|---|---|---|---|---|
| G | 24 | 0.072 | 2.44** | 0.097 | 4.73** | 0.112 | 4.55** | 0.139 | 8.77** |
| I | 2 | 0.822 | 106.95** | 1.758 | 144.99** | 0.694 | 52.67** | 0.998 | 89.02** |
| R : G | 50 | 0.029 | 3.85** | 0.021 | 1.69* | 0.025 | 1.87** | 0.016 | 1.41+ |
| G*I | 48 | 0.011 | 1.41+ | 0.021 | 1.74* | 0.020 | 1.53* | 0.017 | 1.53* |
| REST | 100 | 0.008 | | 0.012 | | 0.013 | | 0.011 | |
| TOTAL | 224 | | | | | | | | |

The coefficients of correlation between all data of single visual scores, SAUDPC and the other field parameters were calculated and the results are presented in table 4. The correlation between the visual evaluation data at the 14th day after inoculation and SAUDPC was −0.96. Highly significant correlations were also detected between the data for SAUDPC and relative ear weight (r = 0.65), relative yield (r = 0.75) and relative 1000 kernel weight (r = 0.62) (P < 0.1 %). A very high correlation coefficient was calculated between the data of relative ear weight and relative yield (r = 0.91). Fig. 2 shows the relationship between the SAUDPC and the relative yield. A regression of relative yield (Y) on the SAUDPC (X) was estimated by $Y = 0.017 + 0.838 \times X$ with a coefficient of determination ($R^2$) of 56 %.

On compairing the data of the field parameters of each inoculum, significant correlations were found (table 5), especially between inoculum 2 (*Fusarium graminearum* from *Triticum durum*) and inoculum 3 (*Fusarium culmorum* from *Triticum aestivum*).

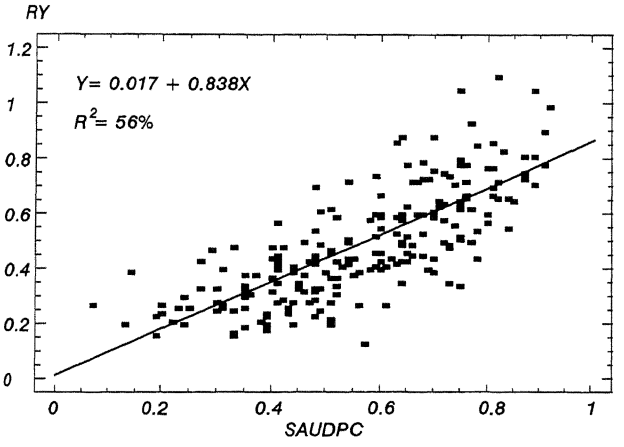


*Fig. 2: Linear regression of the relative kernel yield (RY) on the SAUDPC for the international wheat nursery*

Table 4

*Table of correlations between the data of single visual scores (VS), SAUDPC and other field parameters in the experiment of the international wheat nursery. For all correlation coefficients P< 0.1 % except between RTKW and RKN*

| | $VS_{14}$ | $VS_{18}$ | $VS_{22}$ | SAUDPC | REW | RY | RKN | RTKW |
|---|---|---|---|---|---|---|---|---|
| $VS_{10}$ | 0.83 | 0.71 | 0.63 | −0.90 | −0.54 | −0.64 | −0.52 | −0.45 |
| $VS_{14}$ | | 0.86 | 0.79 | −0.96 | −0.62 | −0.73 | −0.45 | −0.62 |
| $VS_{18}$ | | | 0.88 | −0.91 | −0.65 | −0.72 | −0.39 | −0.64 |
| $VS_{22}$ | | | | −0.84 | −0.65 | −0.71 | −0.34 | −0.66 |
| SAUDPC | | | | | 0.65 | 0.75 | 0.48 | 0.62 |
| REW | | | | | | 0.91 | 0.55 | 0.75 |
| RY | | | | | | | 0.65 | 0.79 |
| RKN | | | | | | | | 0.08 ns |

Table 5

*Results of a correlation analysis between the data of the field parameters of the international nursery for the individual inocula*

| | SAUDPC | | REW | | RY | | RTKW | |
|---|---|---|---|---|---|---|---|---|
| Inocula | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 2 | 0.63*** | | 0.55*** | | 0.28* | | 0.41*** | |
| 3 | 0.74*** | 0.73*** | 0.51*** | 0.72*** | 0.38*** | 0.62*** | 0.51*** | 0.64*** |

## 3.2 Austrian wheat breeding material

The means of the SAUDPC and other field parameters as well as the results of the analysis of variance for SAUDPC are summarized in table 6. A large variability in head blight sensitivity was present with the mean of the SAUDPC ranging from 0.83 for the genotype WW 2 down to 0.18 in the case of DW 10 ($LSD_5 = 0.06$). Some genotypes were significantly better than the best standard Martin. All *Triticum durum* genotypes were very susceptible. Significant differences between the replications and a significant genotype-isolate interaction occurred in this experiment. The field virulencies of the inocula were significantly different ($LSD_5 = 0.01$). The order of the virulence of the inocula was identical to the one found for the international wheat nursery.

Table 6

*Summary of the data for SAUDPC, REW, and RY and analysis of variance table for SAUDPC of the Austrian wheat breeding material. The Triticum aestivum (WW) and Triticum durum (DW) genotypes were separated and sorted in descending order of resistance. Martin, Perlo, Capo, Bonadur, Grandur, Goldur and Astrodur are commercial Austrian varieties used as standard, [1]) mean of three replications, [2]) overall mean of three replications and three isolates*

| | SAUDPC Inoculum | | | | REW | RY |
|---|---|---|---|---|---|---|
| Genotype | 1[1]) | 2[1]) | 3[1]) | Mean[2]) | Mean[2]) | Mean[2]) |
| WW 2 | 0.90 | 0.78 | 0.80 | 0.83 | 0.76 | 0.74 |
| WW 3 | 0.96 | 0.68 | 0.70 | 0.78 | 0.71 | 0.58 |
| WW 1 | 0.81 | 0.64 | 0.74 | 0.73 | 0.69 | 0.59 |
| WW 7 (MARTIN) | 0.84 | 0.64 | 0.65 | 0.71 | 0.60 | 0.46 |
| WW 24 | 0.84 | 0.63 | 0.66 | 0.71 | 0.57 | 0.39 |
| WW 6 (PERLO) | 0.83 | 0.55 | 0.67 | 0.68 | 0.62 | 0.53 |
| WW 5 | 0.78 | 0.57 | 0.64 | 0.66 | 0.56 | 0.43 |
| WW 20 | 0.78 | 0.49 | 0.55 | 0.61 | 0.50 | 0.34 |

| Genotype | SAUDPC Inoculum 1[1]) | 2[1]) | 3[1]) | Mean[2]) | REW Mean[2]) | RY Mean[2]) |
|---|---|---|---|---|---|---|
| WW 4 | 0.76 | 0.43 | 0.62 | 0.60 | 0.56 | 0.44 |
| WW 8 (CAPO) | 0.71 | 0.50 | 0.52 | 0.57 | 0.48 | 0.31 |
| WW 23 | 0.81 | 0.44 | 0.47 | 0.57 | 0.63 | 0.54 |
| WW 25 | 0.74 | 0.44 | 0.52 | 0.57 | 0.66 | 0.52 |
| WW 10 | 0.73 | 0.44 | 0.51 | 0.56 | 0.65 | 0.46 |
| WW 9 | 0.73 | 0.47 | 0.47 | 0.55 | 0.53 | 0.36 |
| WW 14 | 0.64 | 0.49 | 0.47 | 0.53 | 0.41 | 0.21 |
| WW 18 | 0.64 | 0.43 | 0.48 | 0.52 | 0.46 | 0.24 |
| WW 16 | 0.63 | 0.41 | 0.49 | 0.51 | 0.44 | 0.25 |
| WW 21 | 0.65 | 0.46 | 0.43 | 0.51 | 0.54 | 0.33 |
| WW 22 | 0.69 | 0.41 | 0.44 | 0.51 | 0.62 | 0.44 |
| WW 11 | 0.61 | 0.40 | 0.46 | 0.49 | 0.54 | 0.38 |
| WW 13 | 0.59 | 0.40 | 0.48 | 0.49 | 0.41 | 0.27 |
| WW 12 | 0.58 | 0.36 | 0.44 | 0.46 | 0.40 | 0.22 |
| WW 17 | 0.55 | 0.33 | 0.42 | 0.43 | 0.51 | 0.36 |
| WW 19 | 0.53 | 0.32 | 0.42 | 0.42 | 0.59 | 0.45 |
| WW 26 | 0.65 | 0.21 | 0.36 | 0.41 | 0.43 | 0.28 |
| WW 15 | 0.53 | 0.29 | 0.36 | 0.39 | 0.34 | 0.15 |
| DW 18 | 0.64 | 0.38 | 0.37 | 0.47 | 0.52 | 0.34 |
| DW 15 | 0.56 | 0.33 | 0.36 | 0.42 | 0.54 | 0.35 |
| DW 12 (BONADUR) | 0.58 | 0.29 | 0.37 | 0.41 | 0.44 | 0.27 |
| DW 14 | 0.61 | 0.32 | 0.27 | 0.40 | 0.46 | 0.31 |
| DW 19 (GRANDUR) | 0.55 | 0.24 | 0.33 | 0.37 | 0.36 | 0.16 |
| DW 5 | 0.63 | 0.22 | 0.27 | 0.37 | 0.40 | 0.24 |
| DW 11 | 0.51 | 0.27 | 0.29 | 0.36 | 0.36 | 0.24 |
| DW 1 | 0.54 | 0.20 | 0.30 | 0.35 | 0.50 | 0.35 |
| DW 7 | 0.57 | 0.14 | 0.32 | 0.34 | 0.52 | 0.32 |
| DW 13 | 0.51 | 0.21 | 0.23 | 0.32 | 0.38 | 0.21 |
| DW 4 | 0.54 | 0.20 | 0.19 | 0.31 | 0.41 | 0.24 |
| DW 20 | 0.62 | 0.09 | 0.13 | 0.28 | 0.46 | 0.25 |
| DW 16 | 0.46 | 0.19 | 0.21 | 0.28 | 0.38 | 0.13 |
| DW 17 | 0.47 | 0.08 | 0.25 | 0.27 | 0.47 | 0.19 |
| DW 6 | 0.48 | 0.10 | 0.19 | 0.25 | 0.41 | 0.21 |
| DW 9 | 0.40 | 0.15 | 0.13 | 0.22 | 0.36 | 0.14 |
| DW 2 (GOLDUR) | 0.43 | 0.09 | 0.11 | 0.21 | 0.42 | 0.20 |
| DW 8 | 0.43 | 0.03 | 0.17 | 0.21 | 0.39 | 0.14 |
| DW 21 | 0.45 | 0.06 | 0.11 | 0.20 | 0.31 | 0.13 |
| DW 3 (ASTRODUR) | 0.35 | 0.09 | 0.17 | 0.20 | 0.34 | 0.15 |
| DW 10 | 0.29 | 0.07 | 0.18 | 0.18 | 0.33 | 0.10 |
| Mean | 0.62 | 0.34 | 0.40 | 0.45 | 0.49 | 0.32 |

Analysis of variance table

| Source | DF | SS | MS | F | LSD 5 | DF-DN |
|---|---|---|---|---|---|---|
| G | 46 | 11.55 | 0.251 | 3.83** | 0.06 | 94 |
| I | 2 | 6.20 | 3.101 | 1182.61** | 0.01 | 186 |
| R:W | 94 | 0.44 | 0.005 | 1.78** | 0.08 | 186 |
| G*I | 92 | 0.79 | 0.009 | 3.27** | 0.08 | 186 |
| REST | 186 | 0.49 | 0.003 | | | |
| TOTAL | 420 | 19.47 | | | | |

A summary of the data and the results of the analyses of variance of the other field parameters is presented in table 7. Differences between wheat genotypes, between inocula and between replications were significant for all parameters tested except for relative ear length. In the latter case no significant differences between genotypes were detected. A significant but small G*I interaction occurred for the RY and for REW.

Table 7

*Summary of the data of the field parameters and of the analysis of variance of these parameters for the investigated Austrian wheat breeding material, [1]) n= 138; 47 genotypes × 3 replications – 3 missing values*

| Inoculum | | REL 1 | REL 2 | REL 3 | REW 1 | REW 2 | REW 3 | RY 1 | RY 2 | RY 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximum[1]) | | 1.23 | 1.24 | 1.20 | 1.13 | 0.88 | 0.91 | 1.09 | 0.86 | 0.85 |
| Minimum[1]) | | 0.86 | 0.90 | 0.82 | 0.31 | 0.20 | 0.18 | 0.09 | 0.02 | 0.03 |
| Mean[1]) | | 1.01 | 1.02 | 1.01 | 0.59 | 0.42 | 0.45 | 0.44 | 0.23 | 0.28 |
| Source | DF | MS | | F | MS | | F | MS | | F |
| G | 46 | 0.011 | | 1.20 ns | 0.110 | | 6.59** | 0.184 | | 11.95** |
| I | 2 | 0.008 | | 3.62* | 1.081 | | 215.66** | 1.651 | | 232.61** |
| R:W | 94 | 0.009 | | 4.27** | 0.017 | | 3.34** | 0.015 | | 2.16** |
| G*I | 92 | 0.003 | | 1.28+ | 0.009 | | 1.69** | 0.013 | | 1.86** |
| REST | 185 | 0.002 | | | 0.005 | | | 0.007 | | |
| TOTAL | 419 | | | | | | | | | |

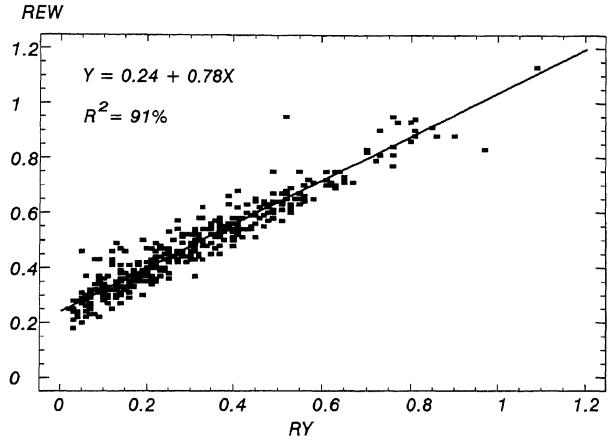


*Fig. 3: Regression of the data of REW on RY for Austrian wheat breeding genotypes*

Table 8

*Table of correlation analysis between the data of single visual scores (VS), SAUDPC and other field parameters for the Austrian wheat breeding material. For all correlation coefficients P< 0.1 %*

| | $VS_{14}$ | $VS_{18}$ | $VS_{22}$ | $VS_{26}$ | SAUDPC | REW | RY |
|---|---|---|---|---|---|---|---|
| $VS_{10}$ | 0.82 | 0.70 | 0.61 | 0.57 | –0.88 | –0.59 | –0.63 |
| $VS_{14}$ | | 0.90 | 0.80 | 0.72 | –0.95 | –0.73 | –0.78 |
| $VS_{18}$ | | | 0.90 | 0.82 | –0.93 | –0.76 | –0.81 |
| $VS_{22}$ | | | | 0.90 | –0.88 | –0.72 | –0.76 |
| $VS_{26}$ | | | | | –0.82 | –0.67 | –0.70 |
| SAUDPC | | | | | | 0.76 | 0.80 |
| REW | | | | | | | 0.96 |

The correlations between single visual evaluation data and SAUDPC as well as field parameters were calculated and the results are presented in table 8. High correlation coefficients were detected between the data for SAUDPC and relative

ear weight (r = 0.76), SAUDPC and relative yield (r = 0.80) and relative ear weight and yield (r = 0.96). As in the case of the international nursery, the results of the SAUDPC correlated best with the second visual evaluation data (r = −0.95). In figure 3 the relative kernel yield data are plotted against REW. A linear regression of relative ear weight (Y) on RY (X) was estimated by $Y = 0.24 + 0.78 \times X$ with an $R^2$ of 91 %.

Table 9 presents the correlation coefficients between the data of SAUDPC and relative yield of each inoculum. Also in this experiment these coefficients proved to be high.

Table 9

*Table of correlation analysis between the data of the SAUDPC and RY for the individual isolates (Austrian wheat breeding genotypes). P< 0.1 % for all coefficients*

| | SAUDPC | | RY | |
|---|---|---|---|---|
| Inoculum | 1 | 2 | 1 | 2 |
| 2 | 0.84 | | 0.71 | |
| 3 | 0.83 | 0.91 | 0.69 | 0.72 |

## 4. Discussion

The genotypes with moderate to good resistance to head blight are of foreign origin. As can be observed in table 2, each country supplied also a susceptible control. In general, the Austrian wheat genotypes did not perform well in this experiment. It should be stressed, however, that the suitable foreign genotypes are lines selected in specific breeding programmes for head blight resistance. This indicates that such breeding programmes were effective in these countries.

In the investigated Austrian wheat breeding material a large variability in head blight susceptibility could be observed. The genotypes WW 2 and WW 3 were significantly better than the best standard Martin (table 6). These genotypes have to be tested again in order to confirm this result. Although we found quantitative differences, no genotype was present with a low sensitivity to head blight. Durum wheat varieties are generally very susceptible to head blight in comparison with *Triticum aestivum*. This has been previously reported also in Austria by ZWATZ (1987, 1988). No genotype with significant better behaviour than the best Durum standard (Bonadur) was found in the *Triticum durum* breeding material. These findings underline again the need for a specific resistance breeding programme.

In both field experiments a good correlation was found between the data for the SAUDPC, relative ear weight and relative yield. From practical point of view the SAUDPC would be preferred for selection purposes because it is less laborious then REW and RY. However, other genetic resistance mechanisms such as tolerance (MESTERHAZY 1990) for example will not be detected. In view of the increasing problems with mycotoxins, the percentage of visually diseased kernels might be important, because this parameter correlates best with the DON content in diseased material (MESTERHAZY 1992).

The results of the SAUDPC were also correlated with the single visual evaluation data. The highest correlation coefficient was obtained between SAUDPC and $VS_{14}$. Based on the results of this investigation, a single visual assessment of the disease symptoms on the 14$^{th}$ day after inoculation might be appropriate. These results are confirmed by more recent data (in preparation) and will save many costly observations particularly in commercial breeding programmes where thousands of breeding units must be tackled.

The inocula used in the field experiments showed variation in the field virulences. The disease reaction of wheat genotypes depends on the aggressiveness of the inocula used for infection. No differences between genotypes will be detected at very low or at very high virulence level. In the first case no or only slight disease symptoms would be observed, in the latter case all genotypes would be completely diseased. Therefore inocula with different aggressiveness were used in the head blight tests. Inoculum 2 was the most aggressive while inoculum 1 induced the weakest head blight symptoms. If we examine the data more closely, it is observed that this sequence does not remain constant for each individual genotype. An example is DW 14 in table 6. Such inversions explain the significant genotype*isolate interaction. This interaction has been described before. It is, however, not stable and therefore no indication for race specific resistance (MESTERHAZY 1983 a, SNIJDERS et al. 1991). The use of different inocula provides a more accurate estimate of the head blight resistance.

The severities of the disease reaction of the wheat genotypes to different *Fusarium* spp. are correlated. A genotype which was more sensitive to *Fusarium culmorum* was also more susceptible to *Fusarium graminearum*. This observation has been reported previously (MESTERHAZY 1983 b, 1987). Selection for head blight resistance against one species resulted also in an increase of resistance against those *Fusarium* spp. not involved in the programme. The genetic background for head blight resistance to different *Fusarium* spp. is presumably identical. As a consequence a breeding programme for head blight resistance can be simplified. Using one or two of the most common Austrian head blight causing species should be sufficient in resistance tests!

As mentioned above, no genotype was present in the investigated native breeding material with a low sensitivity to head blight. A next step in the *Fusarium* resistance breeding programme would be the introduction of more resistant material. Such lines (Nobeokabozu, Sumey-3, Frontana) have been collected, were sown and tested as described. Their outstanding (but not complete) resistance has been confirmed by our results. These varieties will be used in the breeding programme planned for future activities.

**Acknowledgements**

We like to thank Dr. A. MESTERHAZY for the identification of the Fusarium isolates, his critical remarks and interesting discussions. We are also grateful to Miss A. BLAIMAUER and Mr. E. VAVRA for their technical assistance.

## References

ADLER, A., H. LEW and W. EDLINGER, 1990: Vorkommen und Toxigenität von Fusarien auf Getreide und Mais aus Österreich. Bodenkultur *41*, 145—152.

GOCHO, H., 1985: Wheat breeding for scab resistance. Wheat Information Service *60*, 41.

GU, J. Q., 1983: Study of the genetics of resistance of wheat scab. Scientia Agricultura Sinica *6*, 61—64.

LUO, Y., T. YOSHIZAWA and T. KATAYAMA, 1990: Comparative Study on the Natural Occurrence of *Fusarium* Mycotoxins (Trichothecenes and Zearalenone) in Corn and Wheat from High- and Low-Risk Areas for Human Esophageal Cancer in China. Applied and Environmental Microbiology *56*, 3723—3726.

MESTERHAZY, A., 1977: Analysis of symptoms caused by *Fusarium graminearum* Schw. and its relation to powdery mildew infection in wheat. Acta Phytopathologica Academiae Scientiarum Hungaricae *12*, 289—301.

MESTERHAZY, A., 1978: Comparative analysis of artificial inoculation methods with *Fusarium* spp. on winter wheat varieties. Phytopath. Z. *93*, 12—25.

MESTERHAZY, A., 1983 a: Importance of the isolate-genotype interaction in resistance tests with necrotrophic pathogens. Tag.-Ber., Akad. Landwirtsch.-Wiss. DDR, Berlin 216, 561—566.

MESTERHAZY, A., 1983 b: Breeding wheat for resistance to *Fusarium graminearum* and *Fusarium culmorum*. Z. Pflanzenzüchtung *91*, 295—311.

MESTERHAZY, A., 1984: A laboratory method to predict pathogenicity of *Fusarium graminearum* in field and resistance to wheat scab. Acta Phytopath. Acad. Sci. Hung. *19*, 205—218.
MESTERHAZY, A., 1987: Selection of head blight resistant wheats through improved seedling resistance. Plant Breeding *98*, 29—36.
MESTERHAZY, A., 1989: Progress in breeding of wheat and corn genotypes not susceptible to infection by *Fusaria*. In "*Fusarium*, mycotoxins, taxonomy, pathogenicity". Chelkowski J. Ed. Elsevier Amsterdam pp. 357—386.
MESTERHAZY, A., 1990: Factors of resistance to wheat scab. In "Second European Seminar on *Fusarium*, Mycotoxins, Taxonomy, Pathogenicity and *Alternaria* Metabolities", Poznan, Poland. Ed. Szebictko K.
MESTERHAZY, A., 1992: Resistance, pathogenicity and *Fusarium* spp. influencing toxin (DON) contamination of wheat varieties. In "Third European Seminar. *Fusarium*, Mycotoxins, Taxonomy, Pathogenicity and Host Resistance". Eds. Arseniuk E. and Goral T., Radzikow, Poland.
MIEDANER, T. and H. WALTHER, 1987: Ermittlung der *Fusarium*-Resistenz von Weizen im Ährenstadium. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz *94*, 337—347.
MIELKE, H., 1988: Untersuchungen über *Fusarium culmorum* (W. G. Sm.) Sacc. als Fuß- und Ährenkrankheitserreger beim Weizen. Mitteilungen aus der Biologischen Bundesanstalt für Land- und Forstwirtschaft. Berlin-Dahlem. Heft 238. Kommissionsverlag Paul Parey, Berlin und Hamburg.
MILLER, J. D. and R. GREENHALGH, 1988: Metabolites of Fungal Pathogens and Plant Resistance. In "Biotechnology for Crop rotation". Eds. Hedin P. A., Menn J. J. and Hollingworth R. M., 117—129.
NAITO, H., S. MOGI, H. GOCHO and T. HIRAI, 1984: A Simple Method for Evaluation of Varietal Resistance to Scab Caused by *Gibberella Zeae* Petch in Wheat. Bull. Kyushu Natl. Agric. Exp. Stn. *23*, 355—386.
NAKAGAWA, M. O., 1955: Genetic factors affecting ear scab resistance of wheat plants. Japan J. Breeding *5*, 32—38.
NELSON, P. E., T. A. TOUSSOUN and W. F. O. MARASAS, 1986: *Fusarium Species:* an illustrated manual for identification. Pennsylv. State Univ. Press. University Park and London.
SAUR, L., 1991: Recherche de géniteurs de résistance à la fusariose de l'épi causée par *Fusarium culmorum* chez le blé et les espèces voisines. Agronomie *11*, 535—541.
SNIJDERS, C. H. A., 1990 a: Genetic variation for resistance to *Fusarium* head blight in bread wheat. Euphytica *50*, 171—179.
SNIJDERS, C. H. A., 1990 b: The inheritance of resistance to head blight caused by *Fusarium culmorum* in winter wheat. Euphytica *50*, 9—17.
SNIJDERS, C. H. A. and F. A. VAN EEUWIJK, 1991: Genotype x strain interactions for resistance to *Fusarium* head blight caused by *Fusarium culmorum* in winter wheat. Theor. Appl. Genet. *81*, 239—244.
TEICH, A. H., 1989: Epidemiology of wheat (*Triticum aestivum* L.) scab caused by *Fusarium* spp. In "*Fusarium* Mycotoxins, Taxonomy and Pathogenicity" Ed. Chelkowski J. Elsevier Amsterdam, 269—282.
TOMASOVIC, S., 1989: Wheat breeding for resistance to *Fusarium* diseases, especially to *Fusarium graminearum* Schw. Wheat information Service *69*, 13—17.
UTZ, H. F., 1987: Plabstat, a computer program for statistical analysis of plant breeding experiments. Inst. f. Pflanzenztg., Saatgutforsch. u. Populationsgenetik, Univ. Hohenheim.
WORLD HEALTH ORGANIZATION, 1990: Environmental Health Criteria 105. Selected Mycotoxins: Ochratoxins, Trichothecenes, Ergot. World Health Organization, Geneva. 263 pp.
ZHONG, W. Y. and MILLER, J. D., 1987: Screening Techniques and Sources of Resistance to *Fusarium* Head Blight. In "Wheat Production Constraints in Tropical Environments". Proceedings of the International Conference, Chiang Mai, Thailand. Eds. Hettel, G. and J. Keyser, 239—250.
ZHOU, C., S. XIA, C. QIAN, G. YAO and J. SHEN, 1987: On the Problem of Wheat Breeding for Scab Resistance. Scientia Agricultura Sinica *20*, 19—25.
ZWATZ, B., 1987: Ährenfusariose an Weizen — Bemerkungen und Untersuchungen. Der Förderungsdienst *11*, 331—333.
ZWATZ, B., 1988: Ährenfusariose an Sommerweizen. Pflanzenschutz, *4*, 2—3.

(Manuskript eingelangt am 16. November 1992, angenommen am 18. Jänner 1993)

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