Breeding of Winter Wheat (Triticum aestivum L.) for Different Adaptation Types in Multifunctional Agricultural Production

ZOLTAN BEDO

LASZLO LANG

OTTO VEISZ

GYULA VIDA

Breeding of Winter Wheat (*Triticum aestivum* L.) for Different Adaptation Types in Multifunctional Agricultural Production

Z. BEDŐ*, L. LÁNG, O. VEISZ, Gy. VIDA
Agricultural Research Institute of the Hungarian Academy of Sciences, Martonvasar - HUNGARY

Abstract: Germplasm research for sustainable wheat production has undergone a significant development in recent years. Considerable progress has been witnessed in breeding, especially with the selection of winter wheat genotypes with better adaptability to different technological systems in multifunctional agricultural production. The selection of wheat genotypes with abiotic and biotic resistance, stable performance under different fertilizer applications and for various technological systems, will contribute to the development of germplasm with special adaptation type and to that of environment-friendly technologies.

Key Words: wheat, adaptability, breeding, technological systems

Introduction

With the introduction of the sustainability concept considerable changes have taken place in agriculture. In the previous period of Hungarian wheat production the main point considered was yield increase, to supply the population with enough food. Besides this important task, new priorities have been raised nowadays due to increasing concern for environmental protection and healthy food production. These new priorities, which have led to the agricultural sector developing a more multifunctional character, are based on new social demands in relation to food production, where the essential criteria are to provide nutritious foodstuffs free of dangerous substances and to use environment-friendly technologies which ensure sustainability.

Great emphasis is placed on maintaining the ecological equilibrium in the agroecological environment. This purpose is served by the division of agroecological areas into three groups:

1. areas suitable for agricultural production;

2. ecologically sensitive areas where environmental protection takes precedence over agricultural production;

3. areas removed from agricultural production.

In market-oriented agriculture wheat production should primarily be developed on land in the first group, where farmers will generally be sowing wheat varieties suitable for use with high input technologies. However,

the population of ecologically sensitive areas would like to maintain agricultural activities using low input, environment-friendly technologies which are potentially less harmful for the environment.

Wheat breeders carry out research and develop new germplasm adapted for high and low input cropping systems and different agroecological environments. The breeding aims can be divided into two groups. The first includes traits which have equal weight in selection for various adaptation types of winter wheat. For example, resistance to extreme climatic effects in winter is essential if winter wheat is to be successfully grown under any technological conditions. In the present study a comparison was made between the frost resistance of non-intensive and high yielding, intensive types of varieties adaptable to different cropping systems and grown in Hungary over the last 50 years. Besides stress resistance priorities, yield and quality parameters belong to the other group of traits. While the maximization of these traits is the main endeavour in high input technological systems, achieving stability in yield quantity and quality is given priority in a low input environment.

Materials and Methods

The frost resistance of the most important wheat varieties registered in Hungary over the last fifty years was tested in the phytotron of the Agricultural Research

---

* Correspondence to: bedoz@mail.mgki.hu

Institute of the Hungarian Academy of Sciences in Martonvásár using the method elaborated by Tischner et al (1). After germination for 3 days in complete darkness at a day/night temperature of 20°/12 °C and a 12-hour day, wheat seeds with intact rootlets were planted in a 4:1 mixture of earth and sand in wooden boxes, the internal dimensions of which were 38 x 26 x 11 cm. The seeds were planted at a depth of 3.5–4 cm. Each box consisted of nine rows with 20 plants to a row. The varieties were planted in four replications, with 20 plants per replication. After planting, the boxes were kept at room temperature for a day, after which they were transferred to an autumn-winter type growth chamber (Conviron PGV-36), where they were kept for 6 weeks. During this period the temperature, light intensity and length of illumination were gradually reduced, with a weekly change of programme similar to autumn conditions in the field. Every week the temperature was decreased by 1–2 °C and the daylength by 15–45 minutes. Within each weekly programme, the temperature fluctuation, light intensity and daylength were the same each day. The daily temperature fluctuation followed the daily temperature changes experienced in nature.

The preliminary growth stage was followed by 2-phase hardening. The plants were exposed to the first phase in the autumn-winter chamber, where the temperature fluctuated daily between +3 °C and –3 °C with a 21-hour daylength and a photosynthetic photon flux density (PPFD) of 190 µmol·m^{-2}·s^{-1}. This phase lasted for a week. The second phase of hardening, which lasted for 4 days, took place in a frost resistance testing chamber (Conviron C-812) immediately prior to freezing. The temperature was a constant –4 °C with no illumination.

Freezing was carried out in the frost resistance testing chamber set up in the phytotron specifically for this purpose. The temperature was gradually decreased (by 1 °C every hour). Freezing took place at –15 °C for 24 hours. Following the frost treatment the plants were kept in the freezing chamber at +0.5 °C for 2 days. After thawing the boxes were transferred to growth benches (Conviron GB-48). The plants were grown for a further 3 weeks at a day/night temperature of 17°/16 °C, with a 14-hour daylength and a PPFD of 125 µmol·m^{-2}·s^{-1}. At the end of the third week, surviving plants exhibiting renewed growth were clearly distinguishable from those

which had died. The results of freezing are given as a percentage of the plant number prior to freezing. The evaluation of the experimental data was carried out using single-factor analysis of variance. Differences between means were tested using least significant differences (LSD) (P=0.05, 0.01 and 0.001).

Lines in generations F_6–F_7 were tested in two cropping environments in Martonvásár in two seasons, 2000/2001 and 2001/2002. The technological difference between the high and low input environments was given by the quantity of mineral fertilizer applied. The plots in the high input environment were fertilized with 150 kg nitrogen, 80 kg phosphorus and 80 kg potassium active agents per hectare. In the low input environment no mineral fertilizer was applied, but, as in the high input environment, the forecrop was peas and herbicide was used to control weeds.

The grain yield of the lines was used for analysis. The wet gluten content and the gluten index were tested according to the standards ICC 137/1 and ICC 155, respectively. The grain hardness was measured using the SKCS 4100 instrument, based on AACC 55-31, the falling number based on ISO 3093-1982, and the rheological quality with a Brabender farinograph, according to the MSZ 6369-6:1988 standard. The statistical analysis of the summarised data was carried out using the hierarchical cluster analysis module of the SPSS for Windows 11.0 program package.

Results

Frost resistance is an important abiotic resistance trait in both high and low input cropping environments. In the present experiments changes in the frost resistance of newly registered wheat varieties and of those grown most widely in Hungary over the last fifty years were studied under phytotronic conditions. The varieties registered and grown prior to 1975 were chiefly of Soviet or South European origin and included only a small number of West European and Hungarian varieties. The average survival percentage of this group of varieties was 61.6% (Table 1). During this period great differences could be observed between the frost resistance levels of various groups of varieties.

The most rapid increases in yield in Hungarian wheat production were witnessed from the mid-seventies till the end of the eighties. During this time intensive type, high yielding South European and Hungarian varieties were

Table 1. Average phytotronic frost survival of wheat varieties registered in different periods in Hungary (Martonvásár, 2003).

Period of registration	Survival (%)	No. of varieties
Before 1975	61.6	22
1975 – 1990	54.3	33
1991 – 2002	68.2	35
$LSD_{5\%}$	10.0	

grown most widely and the majority of Soviet varieties lost ground, leading to a non-significant reduction in the mean frost resistance of the varieties registered between 1975 and 1990 compared to that of the less intensive varieties grown in the previous period.

The number of registered varieties increased after 1990. Due to the reduced application of chemicals in commercial wheat production, preference was again given to less intensive varieties. The average frost resistance of these varieties and of those registered most recently has increased non-significantly compared with both the previous periods, and the survival percentage is now close to 70%.

Regardless of this trend, frost-sensitive and frost-resistant varieties were to be found among both the old, non-intensive type of wheats and the intensive varieties. Over the last decade the average level of frost resistance has non-significantly increased despite the substantial increase in the number of varieties. If the frost resistance of varieties successfully grown over the last 50 years is examined, it can be seen that the vast majority had good resistance. These varieties include Bezostaya 1, Yubileinaya 50, Martonvásári 4, Martonvásári 15 and Martonvásári 23. However, two important varieties in Hungarian wheat production, Bankúti 1201 and GK Öthalom, had a medium level of frost resistance, which represents the minimum requirement for frost survival breeding under Central European conditions.

The greatest differences in frost resistance could be observed when the varieties were grouped according to where they were bred. Varieties registered in Hungary, but bred in countries to the south or west of Hungary had lower frost resistance on average than those bred in Hungary or the Soviet Union. Even within Hungary the varieties could be grouped on the basis of frost resistance according to the breeding institute. As is clear from the

data in Table 2, among the varieties grown in Hungary, those with the best frost resistance originated from Eastern Europe, chiefly from the ex-Soviet Union. These were followed by varieties bred in Martonvásár. The least frost-resistant varieties were those bred in Southern Europe, which were widely grown in Hungary mainly in the 70s and 80s. The average frost resistance of varieties from Western Europe was significantly better than that of the Southern European varieties, but was lower than that of Bánkúti 1201, a variety grown in Hungary for thirty years, with a moderate level of frost resistance.

Table 2. Average frost resistance of wheat varieties state registered in Hungary and grouped according to site of origins.

Breeding location	Survival percentage	No. of varieties
Western Europe	41.1%	6
Southern Europe	23.7%	14
Eastern Europe	86.3%	8
Hungary	69.9%	60
Martonvásár	75.4%	41
Not Martonvásár	58.2%	19
$LSD_{5\%}$	10.0%	

The yield performance and quality traits of advanced lines in the F_6–F_7 generations (Table 3) were tested at two technological levels, in high and low input environments in Martonvásár for two years. The effect of the two technologies is well reflected in the fact that the average yield of lines in the fertilized experiment was 4.52 t/ha, averaged over two years, while in the unfertilized, low input environment, this figure was 4.27 t/ha, only 5.5% lower. Among the quality traits, the mean gluten content was 36.8% in the high input experiment, 2.0% more than under low input conditions. The rheological value was higher in the low input environment.

The breeding lines were then grouped according to yield performance and quality traits on the basis of cluster analysis on the growing site data. The grouping was carried out using the Ward method, based on the Euclidean squared distances.

Table 3. Average performance of F_6–F_7 lines in different cropping systems (Martonvásár 2001 – 2002)

Environment	Yield t/ha	Gluten content %	Farinograph value	Gluten index	Falling number sec
High input	4.52	36.8	72.5	75.0	396
Low input	4.27	34.8	79.1	80.2	393

In the cluster analysis the lines were grouped according to their performance in the high input, the low input and both cropping environments. The results are presented in Figures 1, 2 and 3. It is clear from the results that the performance of the lines differed considerably in the high and low input environments. At the same time, it can be seen that analysis based on the average performance in both environments gave results similar to those obtained for the low input environment, since a number of groups formed in the joint cluster analysis were also to be found in the analysis of the low

input technology. For instance, lines 04-02, 07-02 and 12-02 formed a group in both the low input analysis and the joint analysis. Lines 09-02, 14-02 and 06-02, and lines 11-02 and 15-02 also formed groups in both analyses.

Discussion

According to a survey carried out by Braun et al. (2) the most important breeding aims for the next few years in the breeding programmes responsible for 90% of the
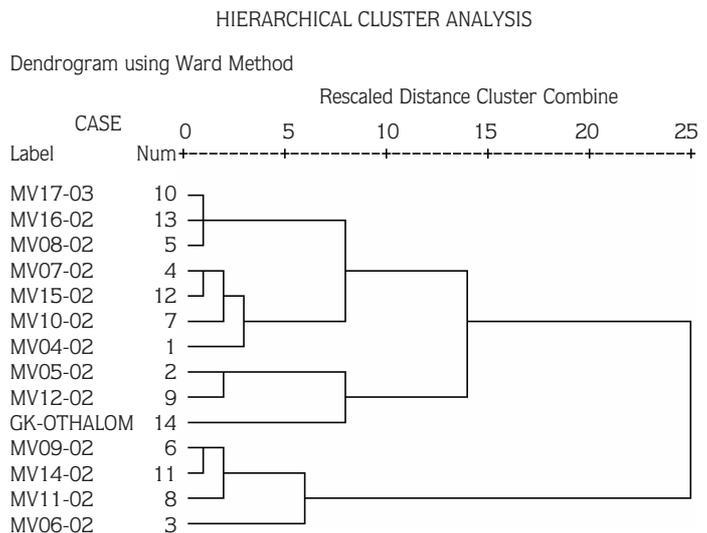
HIERARCHICAL CLUSTER ANALYSIS

Dendrogram using Ward Method

Figure 1. Grouping of lines in high input environment.

HIERARCHICAL CLUSTER ANALYSIS

Dendrogram using Ward Method
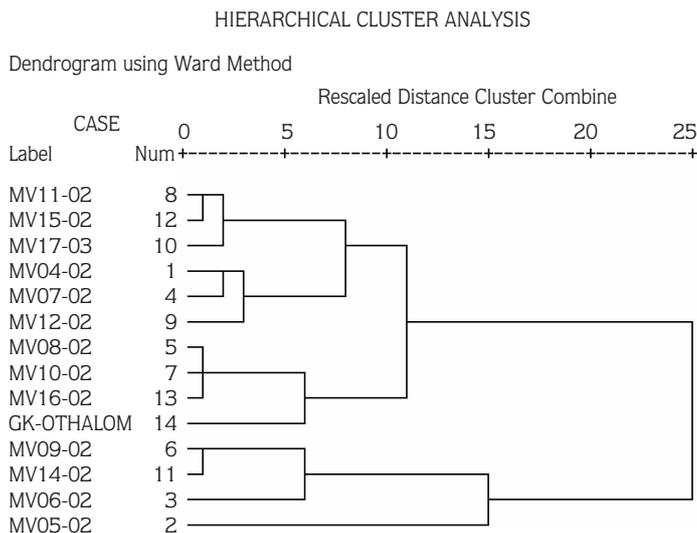
Figure 2. Grouping of lines in low input environment

HIERARCHICAL CLUSTER ANALYSIS

Dendrogram using Ward Method

Rescaled Distance Cluster Combine

```
         CASE      0         5        10        15        20        25
Label    Num  +---------+---------+---------+---------+---------+
MV09-02    6
MV14-02   11
MV06-03    3
MV10-02    7
MV15-02   12
MV11-02    8
MV08-02    5
MV16-02   13
MV17-03   10
MV04-02    1
MV07-02    4
MV12-02    9
MV05-02    2
GK-OTHALOM 14
```
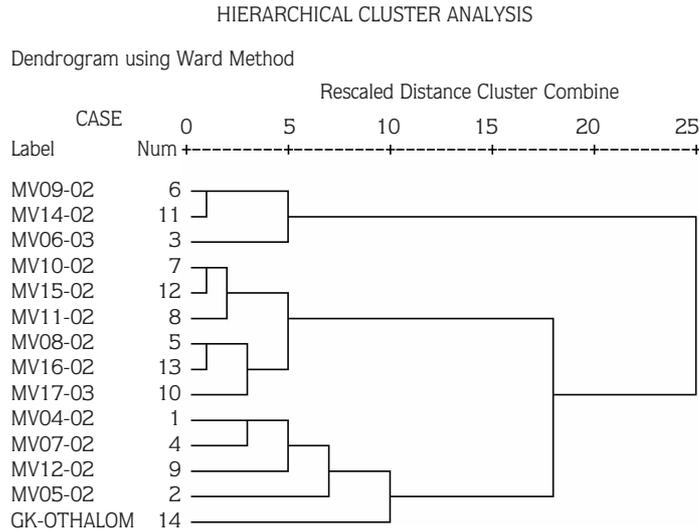
Figure 3. Grouping of lines in average in two locations

winter or facultative wheat-growing areas of the world will be an increase in yield potential and the improvement of traits involved in yield stability. Among the wheat diseases, leaf rust (*Puccinia recondita*), *Fusarium* spp. and *Septoria* spp. will be given priority, while winter hardiness and drought tolerance are the major goals in abiotic stress research. Breeding for N and P use efficiency and the development of varieties with stable quality across environments will gain greater importance. The results of the present survey also indicate that yield performance continues to be of importance in wheat breeding, though it will be necessary to improve traits involved in yield stability if further yield increases are to be achieved. The improvement of yield stability is of special importance in a low input environment, where the technological system only allows the use of a limited quantity of pesticide and the crops are exposed to many unfavourable conditions.

For many years experiments have been underway in Martonvásár in the field and phytotron on the selection of different adaptation types for various cropping systems. The breeding aims can be divided into two groups in this respect. The first includes traits which have equal weight in selection for various adaptation types of winter wheat under Central European environments, such as resistance to abiotic stress, which is an important selection criterion in any technological system. Resistance to extreme climatic effects in winter is essential if winter wheat is to

be successfully grown under any technological conditions. The steppe-type varieties which were widely grown before intensive, high-yielding wheat varieties were introduced have the best adaptation to low input technologies and also have the best frost resistance. The Martonvásár breeding programme has made great use of these varieties and a similar level of frost resistance has been achieved in some varieties. These include the old non-intensive variety Martonvásári 4. Martonvásári 5, Martonvásári 9 and Martonvásári 12, which have the same pedigree, also belong to this group. The varieties selected over the last 15 years have a smaller proportion of steppe-type Soviet varieties in their pedigrees. Nevertheless, the frost resistance of Mv Pálma, Mv Vilma, Mv Optima, Mv Mezofold, Mv Palotás, Mambo, Mv Marsall and Mv Emese is similar to that of Bezostaya 1.

Prior to the 1990s high rates of mineral fertilizer were applied in Hungarian wheat production. Due to the steep rise in energy costs over the last decade, the quantity of fertilizer dropped by some 70%, and is still not increasing to any great extent. In many regions of the country there has been a change from high input to low input cropping technologies. This trend is reflected in the new varieties: the average plant height has become taller, the yield potential has not increased and the technological quality depends more on the genotype than on a high level of fertilizers. From among the fungal diseases powdery mildew is today less important than 20 years

ago in high input cropping environments. The selection of genotypes with different types of adaptability is required to suit the environmental conditions in production regions with different agroecological potential. In addition to varieties with wide adaptability, the development of varieties with special adaptability to low input technologies should be given priority under the present changed cropping conditions.

Calderini and Slafer (3) consider that the increase in yield potential is particularly pronounced in high-yielding environments with large technical inputs. This trend was associated with a decline in yield stability in the case of modern high-yielding varieties. Under less favourable environments, such as low input cropping systems, the selection of genotypes for yield and quality stability has primary importance.

One of the most vulnerable points of low input technologies is that the technological quality, particularly the protein content and protein quality, may also decline together with the yield. It is essential to select genotypes whose yield and technological quality are more stable than average in a low input environment. In France, for example, the variety Renan is recommended for this purpose in low input wheat production (4). It should be noted, however, that there are considerable differences between the low input and organic farming technologies, which are based on quite different concepts.

One important characteristic of wheat varieties suitable for production in a low input environment is the more efficient use of nitrogen and other nutrients. Significant differences can be demonstrated between the different varieties and in the variety × environment interaction for dry matter and nitrogen accumulation. The nitrogen grain filling rate and duration exhibited greater variability than the dry matter grain filling rate (5). The investigation of these traits and of their interaction with the environment are of enhanced importance in selection for stable technological quality.

References

Braun, H.J., Ekiz, H., Eser, V., Keser, M., Ketata, H., Marcucci, G., Morgounov, A., and N. Nercirci. 1998. Breeding priorities of winter wheat programs. H.J. Braun et al. (eds.), Wheat: Prospects for Global Improvement, 533-560.

Calderini, D.F., and G.A. Slafer. 1999. Has yield stability changed with genetic improvement of wheat yield? Euphytica, 107:1, 51-59.

Charmet, G. 2003. personal communication

Roberts, N., Hennequet, C. and P. Bérard. 2001. Dry matter and nitrogen accumulation in wheat kernel: genetic variation in rate and duration of grain filling. J. Genet. & Breed. 55: 297-305.

Tischner, T., Köszegi, B. and O. Veisz. 1997. Climatic programmes used in the Martonvásár phytotron most frequently in recent years. Acta Agronomica, 45: 85-104.