*Agriculture (Poľnohospodárstvo), 55, 2009 (1): 26-32*

# BREEDING PROGRESS IN GRAIN YIELD AND QUALITY OF WINTER WHEAT CULTIVARS

## SELEKČNÝ POKROK V ÚRODE A V KVALITE ZRNA ODRÔD PŠENICE LETNEJ F. OZIMNEJ

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UŽÍK, M. – ŽOFAJOVÁ, A. – HANKOVÁ, A.: Breeding progress in grain yield and quality of winter wheat cultivars. Agriculture (Poľnohospodárstvo), vol. *55*, 2009, N. 1, pp. 26–32.

With the aim to investigate breeding progress in grain yield and the quality of new local and foreign winter wheat cultivars in comparison to cultivar Viginta (registered in 1984) and their reaction to different N rates, four individual field experiments were established. Cultivar Viginta and four different cultivars were included in each experiment, in all 17 cultivars. Experiments 1 and 2 were established in six fertilisation variants with increasing N rates (0, 40, 80, 120, 150 kg.ha$^{-1}$) combined with PK fertilisers, experiments 3 and 4 were on the similar variants of N rates without PK fertilisers. Mineral N nutrition was highly effective. As optimal and economic effective N rates for grain yield were from 40 to 80 kg.ha$^{-1}$, which increased grain yield compared to 45 years of non fertilised control variant on 170%. The modern cultivars responded to N fertilisation more positively than cultivar Viginta. A minimal rate from 80 to 120 kg N.ha$^{-1}$ is required to guarantee quality parameters for food utilisation. N 40 kg.ha$^{-1}$ increased grain yield, but not quality parameters. In the set of 17 cultivars, none exceeded cultivar Viginta in all the evaluated traits – grain yield, protein content, wet gluten, hardiness, sedimentation index. Breeding progress over the past 20–25 years was manifested only partially – in some cultivars in any trait alternatively, that is breeding progress in grain yield was compensated by decreasing parameters of quality and opposite.

Key words: wheat, cultivars, N fertilisation, grain yield, quality

In the last century increased demands on the food market and the relative sufficient N in the form of fertilisers allowed for the selection of winter wheat cultivars with high grain yield, due to high N uptake, which was accompanied by the decreasing of N utilisation and compared to expectation also the decreasing of grain quality (Užík and Žofajová 2003).

For permanent sustainability of farming the aim of plant breeding is to develop genotypes with a high uptake and utilisation of nutrition and water (Rajaram 2000). Actual modern cultivars are inconvenient neither for ecological farming, which is the condition of permanent sustainability, nor alternative utilisation, where the cultivars with low N grain concentration are required.

Knowledge about changes in physiological

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traits connected with genetic gain of yield potential for the certain period are key for the understanding of factors limiting grain yield and for formulation of the future breeding strategy. The analysis of the historical assortment of wheat indicates, that the increasing of grain yield was achieved by a combination of improved rate growth before anthesis, what was manifested in grain number per $m^{-2}$ (Užík and Žofajová 2003) and by higher sources of water soluble carbohydrates in the stems for grain formulation (Shearman et al. 2005).

Harvest index and grain number per area were increased, but 1000 grain weight was less changed. Modern cultivars nourish more grains and utilise N more effective than old cultivars (Brancourt-Hulmel et al. 2003). Breeding progress in grain yield is reduced by negative relation between grain yield and protein content (Užík and Žofajová 2003). The reasons for the negative relationship between grain yield and its quality are not clear. More aspects such as physiological, genetic and selective ones can be considered as the starting point in the formulation of a working hypothesis.

The aim of the research was to find out the breeding progress in grain yield and in quality traits of newer local and foreign winter wheat cultivars compared to cultivar Viginta and their reaction on the different N fertiliser rates.

## MATERIAL AND METHODS

Four separate experiments were modelled on the long term stationary experiment in Vígľaš-Pstruša with 12 fertilisation variants in four replications in the vegetation 2005/06 with the aim to evaluate a larger number of winter wheat cultivars on the reaction on N fertilisation. Management of the experiment was described in detail in the paper Užík et al. 2008.

The experiments 1 and 2 were established on the six variants of fertilisation with increased N rates (0, 40, 80, 120, 150 $kg.ha^{-1}$) combined with PK fertilisers and the experiments 3 and 4 were on the similar variants N rates without PK fertilisers (Table 2, 3). In each experiment cultivar Viginta was included (registered in SR in 1984) and always four different winter wheat cultivars, total 17 cultivars (Table 1). The insertion of cultivar Viginta into each experiment and in all the replications allowed with certain assumptions to evaluate all four cultivar sets as one set by the methods of the general linear model.

The local and foreign winter wheat cultivars with different declared quality parameters were included in the experiments (Table 1). Evaluation of grain yield and quality parameters (protein content, wet gluten, sedimentation index, grain hardness) determined by NIRS instrument are presented.

Statistical analyses were performed by the software package *Statistics plus for Windows.*

## RESULTS AND DISCUSSION

Interaction cultivar x fertilisation was not possible to determine for the whole cultivar set as the different cultivars were in each subset (Table 1). By the analyse of separate subsets significant interaction was found between cultivar and fertilisation for each trait besides wet

T a b l e 1

List of cultivars evaluated in the experiments

| Experiment 1 | | | Experiment 2 | | | Experiment 3 | | | Experiment 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Cultivar | Baking quality | No. | Cultivar | Baking quality | No. | Cultivar | Baking quality | No. | Cultivar | Baking quality |
| 1 | Viginta A | 7 | 6 | Viginta A | 7 | 11 | Viginta B | 7 | 16 | Viginta B | 7 |
| 2 | Petrana | 7 | 7 | Akteur | 9–8 | 12 | Cubus | 7–6 | 17 | Bardotka | 7–6 |
| 3 | Barroko | 7–6 | 8 | Ebi | 9–8 | 13 | Sulamit | 9–8 | 18 | PS–15 | – |
| 4 | Bosorka | 7 | 9 | Rapsodia | 4 | 14 | Markola | 5 | 19 | PS–6/08 | – |
| 5 | Venistar | 4 | 10 | Malvína | x | 15 | Meritto | 6 | 20 | PS–3/09 | – |

gluten, the results are not presented but considered in the interpretation of the results.

The analysis of data of cultivar Viginta, included in all fertilisation variants, indicated no significant differences in evaluated traits (Table 2) and therefore it is possible to evalu-

T a b l e 2

Average grain yield and quality parameters of cultivar Viginta according to fertilization variant in % (N0 = 100%) (the average of 4 replications)

| Fertilization variants | Grain yield [t.ha$^{-1}$] | Protein content [%] | Wet gluten [%] | Sedimentation index [ml] | Grain hardiness [%] |
|---|---|---|---|---|---|
| 1 N0 abs. | 4.824 | 8.82 | 19.22 | 32.78 | 56.27 |
| 1 N0 % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2 N0 M* | 101.6 | 98.6 | 96.4 | 99.9 | 99.0 |
| 3 N0 PK | 91.7 | 100.0 | 99.7 | 76.3 | 100.8 |
| 4 N40 | 128.8 | 103.4 | 100.2 | 97.7 | 102.8 |
| 5 N40 PK | 127.4 | 102.4 | 109.2 | 94.7 | 99.8 |
| 6 N80 | 144.5 | 113.4 | 114.3 | 116.4 | 105.5 |
| 7 N80 K | 170.8 | 123.6 | 132.1 | 117.8 | 108.6 |
| 8 N80 P | 153.7 | 114.6 | 105.1 | 110.4 | 105.5 |
| 9 N80 PK | 156.5 | 112.3 | 117.8 | 109.8 | 105.7 |
| 10 N120 | 157.2 | 124.2 | 130.3 | 133.0 | 111.7 |
| 11 N120 PK | 168.0 | 119.2 | 135.3 | 129.2 | 109.2 |
| 12 N150 PK | 164.9 | 121.7 | 139.9 | 128.2 | 114.5 |
| $\overline{x}$ | 138.8 | 111.1 | 115.0 | 109.5 | 105.3 |
| $LSD_{0.05}$ [%] | 27.8 | 10.0 | 22.6 | 39.4 | 7.2 |
| $\overline{x}$ | 6.696 | 9.801 | 22.11 | 35.89 | 59.25 |
| $LSD_{0.05}$ [abs.] | 1.342 | 0.883 | 4.35 | 12.92 | 4.07 |

* manure

LSD – least significant difference

T a b l e 3

Average grain yield and quality parameters of winter wheat cultivars according to fertilization variants in % (N0 = 100%) (the average of 17 cultivars)

| Fertilization variants | Grain yield [t.ha$^{-1}$] | Protein content [%] | Wet gluten [%] | Sedimentation index [ml] | Grain hardiness [%] |
|---|---|---|---|---|---|
| 1 N0 abs. | 4.480 | 8.99 | 17.48 | 33.44 | 62.52 |
| 1 N0 % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2 N0 M* | 108.4 | 102.6 | 116.4 | 100.9 | 101.8 |
| 3 N0 PK | 108.4 | 102.6 | 113.6 | 94.7 | 103.5 |
| 4 N40 | 130.8 | 102.4 | 106.9 | 112.5 | 104.1 |
| 5 N40 PK | 134.7 | 104.8 | 118.6 | 102.7 | 104.1 |
| 6 N80 | 151.3 | 111.9 | 122.4 | 118.4 | 107.7 |
| 7 N80 K | 170.4 | 118.1 | 133.2 | 128.0 | 110.7 |
| 8 N80 P | 162.6 | 109.9 | 119.5 | 116.6 | 106.4 |
| 9 N80 PK | 165.7 | 112.9 | 136.2 | 118.8 | 107.5 |
| 10 N120 | 162.5 | 120.9 | 147.1 | 134.6 | 114.9 |
| 11 N120 PK | 173.2 | 119.7 | 147.8 | 132.0 | 112.9 |
| 12 N150 PK | 175.7 | 123.6 | 156.0 | 133.3 | 113.6 |
| $\overline{x}$ | 144.5 | 111.0 | 126.4 | 117.6 | 109.5 |
| $LSD_{(0.05)}$ (%) | 17.40 | 5.49 | 14.07 | 22.40 | 3.93 |
| $\overline{x}$ | 6.477 | 9.98 | 22.10 | 39.35 | 68.44 |
| $LSD_{(0.05)}$ (abs.) | 0.78 | 0.49 | 2.46 | 7.51 | 2.58 |

* manure

LSD – least significant difference

ate all four sets, although with restriction as one set.

*The effects of fertilisation*

Detailed analyse of all cultivar set showed that some cultivars utilised higher N rates for grain yield production and also for quality more effectively than cultivar Viginta (Table 3, 2). While cultivar Viginta achieved maximal grain yield and quality parameters at N 80 kg.ha$^{-1}$ eventually to 120 kg N.ha$^{-1}$ (Table 2), the average of all cultivars in all evaluated traits was the highest only at N 150 kg.ha$^{-1}$ (Table 3), what designates that newly registered cultivars responded to N fertilisation more positively than cultivar Viginta.

*The effects of cultivars* (Table 4, Fig. 1).

The choice of cultivar in the experiment was based on the declared characteristics with the aim that the evaluated cultivar set was representative and sufficiently diversified in grain yield and quality parameters. In the evaluated set in grain yield exceeded the cultivars Malvína, Petrana, Akteur (Fig. 1a) and the cultivars Barroko, Bosorka, Sulamit, Markola and Bardotka had lower grain yield, but by contrast exceeded in the quality parameters (Fig. 1a, 1b). Comparing to cultivar Viginta, we can state that in the evaluated set, no cultivar was found that significantly exceeded it in the all traits. Lower breeding progress in grain yield in the last two decades was observed by several authors (Reynolds et al. 2005) and in any case it is not comparable with breeding progress in the years after the Second World War (Užík and Žofajová 2003), accompanied by decreasing of quality parameters. On the contrary, partially in the separate traits breeding progress was observed for example in the grain yield – cultivar Malvína, in the quality parameters – cultivar Bosorka, exceeded in the all quality traits, however

T a b l e 4

Average grain yield and quality parameters of winter wheat cultivars (6 fertilization variants and 2 replications) in % (Viginta = 100%)

| Cultivar | Grain yield [t.ha$^{-1}$] | Protein content [%] | Wet gluten [%] | Sedimentation index [ml] | Grain hardiness [%] |
|---|---|---|---|---|---|
| Viginta abs. | 6.697 | 9.80 | 22.11 | 35.89 | 59.25 |
| Viginta % | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Petrana | 101.3 | 100.3 | 105.8 | 89.2 | 104.6 |
| Barroko | 87.4 | 107.8 | 119.5 | 132.2 | 127.2 |
| Bosorka | 85.7 | 110.5 | 122.0 | 134.8 | 136.3 |
| Venistar | 97.3 | 97.0 | 106.8 | 73.3 | 103.7 |
| Cubus | 98.2 | 100.3 | 98.4 | 134.5 | 130.4 |
| Sulamit | 87.3 | 101.9 | 97.9 | 111.0 | 126.9 |
| Markola | 93.5 | 105.5 | 90.7 | 107.4 | 103.2 |
| Merito | 101.6 | 98.3 | 91.3 | 125.6 | 123.1 |
| Akteur | 103.9 | 101.2 | 98.0 | 101.9 | 119.2 |
| Ebi | 93.7 | 103.9 | 97.4 | 115.9 | 120.4 |
| Rapsodia | 93.7 | 100.9 | 98.4 | 110.3 | 112.0 |
| Malvína | 108.1 | 100.1 | 88.6 | 108.8 | 108.5 |
| Bardotka | 89.9 | 106.4 | 104.1 | 109.1 | 115.7 |
| PS-11 | 101.4 | 92.1 | 80.7 | 105.4 | 107.6 |
| PS-6/04 | 103.0 | 101.6 | 98.1 | 107.0 | 110.9 |
| PS-3/05 | 98.2 | 103.8 | 101.8 | 97.8 | 112.9 |
| $\bar{x}$ | 96.7 | 101.8 | 99.9 | 109.6 | 115.5 |
| $LSD_{(0.05)}$ [%] | 11.68 | 4.71 | 10.41 | 19.50 | 4.07 |
| $\bar{x}$ | 6.477 | 9.98 | 22.10 | 39.35 | 68.44 |
| $LSD_{(0.05)}$ [abs.] | 0.78 | 0.46 | 2.30 | 7.02 | 2.41 |

LSD – least significant difference

at the expense off by 15% lower grain yield compared to the cultivar Viginta (Table 4, Fig. 1). From the results it followed that selection pressure on quality traits was practised mainly on the sedimentation index, nearly all cultivars except for cultivars Petrana and Venistar had higher values than cultivar Viginta.

The analyse indicates that the permanent restriction of breeding progress has a negative relationship between grain yield and quality. This relationship is conditioned by nutrition and genotype. In Figure 2 it is shown that between grain yield and quality traits there are positive correlations which are conditioned by N fertilisation (a, b, c). By the increasing of N rates not only grain yield was increased but also the values of quality traits. The dilution effect of N substances compared with carbon compounds was not observed. Correlation between grain yield and quality parameters are negative in the case conditioned by genotypes (Fig. 2d, e, f).

Correlations among grain yield and quality traits in the evaluated cultivar set vary in dependence on N fertiliser rates (Table 5). The negative value of correlation coefficient was increased by the increasing of N rates. The reasons are not clear. Simultaneous selection of genotypes in the environments with different N soil status is recommended. Selection on the higher efficiency of N uptake and utilization is proposed as starting point by the several authors. Environment and mainly N fertilisation increase not only variability of total proteins, but also their composition and their quality (Johansson et al. 2004). For breeding strategy it is essential to estimate the portion of environment, eventually of nutrition, of breeding and genotype on the variability of separate components of protein, but also on wet gluten, on sedimentation index and more quality traits.

T a b l e 5

Correlations among grain yield and wheat grain quality traits on different N fertilization levels (n=20 winter wheat cultivars)

| N fertilization level | Protein content [%] | Wet gluten [%] | Sedimentation index [ml] |
|---|---|---|---|
| Whole set | –0.611$^{++}$ | –0.600$^{++}$ | –0.408 |
| 0 kg.ha$^{-1}$ | –0.090 | –0.134 | –0.207 |
| 40 kg.ha$^{-1}$ | –0.252 | –0.004 | –0.239 |
| 80 kg.ha$^{-1}$ | –0.051 | 0.045 | –0.373 |
| 120 kg.ha$^{-1}$ | –0.468$^{+}$ | –0.155 | –0.610$^{++}$ |

$^{+}$P<0.05 $^{++}$ P<0.01

P – effect significant at the level a = 0.05 or a = 0.01

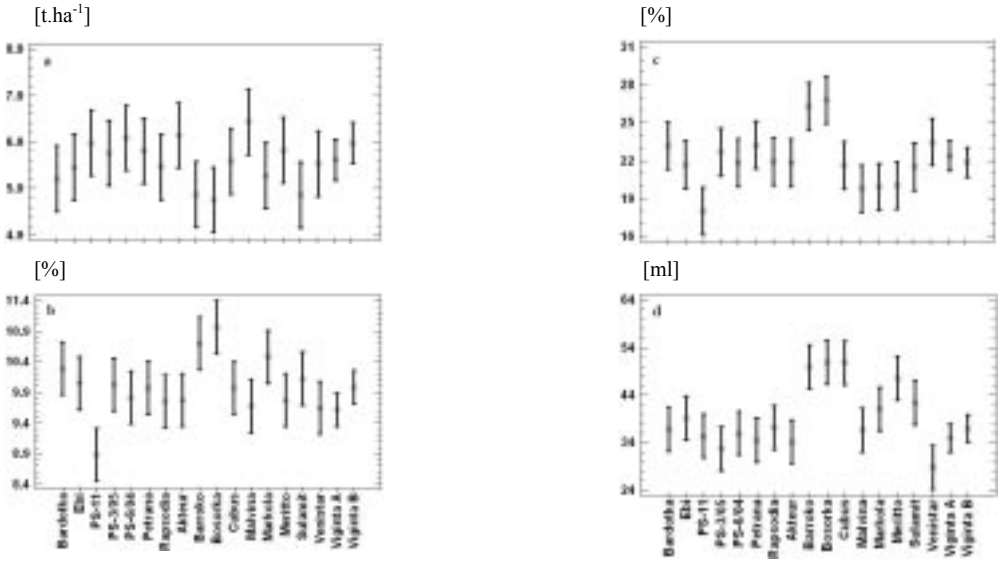


Fig. 1. Average values of traits of winter wheat cultivars: a – grain yield, b – protein content, c – wet gluten content, d – sedimentation index

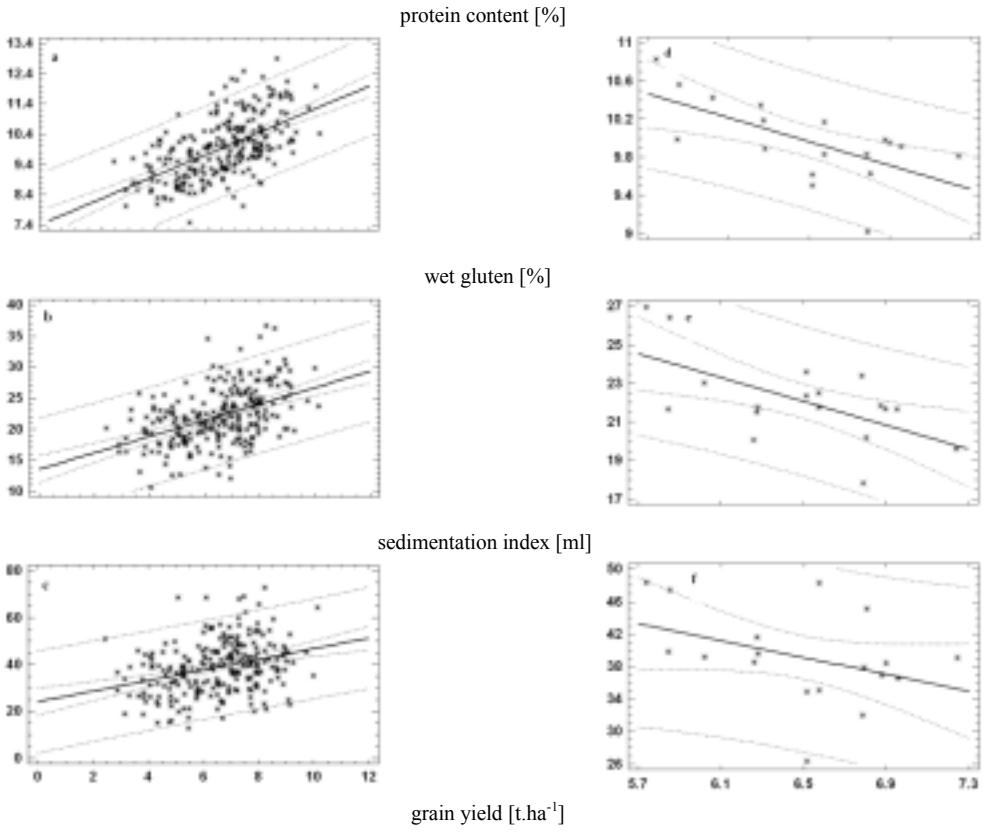


Fig. 2. Correlations among grain yield and wheat grain quality traits conditioned by environment (N fertilizer) (a, b, c) and genotype (d, e, f)

## CONCLUSION

Mineral N nutrition of winter wheat was highly effective. As optimal and economically effective N rate for grain yield was from 40 to 80 kg.ha$^{-1}$, for quality traits required for food processing minimal rate from 80 to 120 kg N.ha$^{-1}$ is needed. In the set of 17 cultivars none exceeded cultivar Viginta in the all evaluated traits. Breeding progress during the last 20–25 years was manifested compared to control cultivar Viginta only partially – in some cultivar in the certain trait, alternatively i.e. breeding progress in grain yield was compensated by the decreasing of quality parameters and on the contrary.

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## SÚHRN

S cieľom zistiť selekčný pokrok v úrode zrna a v ukazovateľoch kvality novších domácich a zahraničných odrôd pšenice letnej f. ozimnej v porovnaní s odrodou Viginta a ich reakciu na rôzne dávky N hnojív sme založili štyri samostatné pokusy. V každom pokuse sme zaradili odrodu Viginta a štyri vždy iné odrody, spolu 17 odrôd. Pokusy 1 a 2 sme založili na šiestich variantoch hnojenia so stúpajúcimi dávkami N (0, 40, 80, 120, 150 kg.ha$^{-1}$) kombinovanými PK hnojivami a pokusy 3 a 4 boli na podobných variantoch N dávok bez PK hnojív. Minerálna N výživa pšenice letnej f. ozimnej bola vysoko efektívna. Ako optimálna a ekonomicky efektívna dávka N pre úrodu zrna bola od 40 do 80 kg.ha$^{-1}$, ktorá zvýšila úrodu zrna oproti 45 rokov nehnojenému kontrolnému variantu na 170 %. Moderné odrody pozitívnejšie reagovali na N hnojenie než odroda Viginta. Pre zabezpečenie požadovaných parametrov kvality pre potravinárske využitie je požadovaná minimálna dávka od 80 do 120 kg N.ha$^{-1}$. Dávka N do 40 kg.ha$^{-1}$ sa síce pozitívne prejavila na zvýšení úrod zrna, ale nie na zvýšení parametrov kvality. V súbore 17 odrôd žiadna neprekonávala odrodu Viginta vo všetkých znakoch – v úrode zrna, v obsahu bielkovín, v mokrom lepku, v tvrdosti zrna a v hodnote sedimentačného indexu.

Kľúčové slová: pšenica, odrody, N hnojenie, úroda zrna, kvalita