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# EFFECT OF DIFFERENTIATED PHOSPHORUS AND POTASSIUM FERTILIZATION ON WINTER WHEAT YIELD AND QUALITY

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Abstract

This study was conducted in 2007-2010, on a farm near Śrem (south of Poznań, Poland). A field experiment was set up in a randomized block design with four replications for each combination tested. The effects of differentiated rates of phosphorous and potassium applied together with a fixed level of nitrogen and magnesium fertilization were investigated. During the experiment, the winter wheat grain yields were high and significantly different between both between fertilizer treatments and when compared with the control. Correlation analysis on relationships between grain yield and nutrient content in wheat leaves at the beginning of stem elongation stage (BBCH31) showed significant relationships for phosphorous, calcium, magnesium, zinc and manganese. Regression analysis proved that the content of zinc in leaves at the BBCH31 stage was the main factor which determined winter wheat grain yield. Furthermore, mineral fertilization significantly increased the content of protein and gluten when compared with the control objects, whereas no significant differences were observed among the fertilized objects. Statistically significant relationships were found between leaf content of N, P, Mg, Zn and Mn at BBCH31 and the accumulation of protein and gluten in wheat grain. Protein and gluten in grain depended on the content of magnesium in leaves at the beginning of stem elongation stage. Weather conditions as a factor significantly influenced grain size uniformity while mineral fertilization had no influence on this trait.

Key words: winter wheat, phosphorus and potassium rates, gluten, protein, grain size uniformity.

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**WPŁYW ZRÓŻNICOWANEGO NAWOŻENIA FOSFOREM I POTASEM NA PLON I JAKOŚĆ PSZENICY OZIMEJ**

Abstrakt

Badania przeprowadzono w latach 2007-2010 w gospodarstwie rolnym w okolicach Śremu. Doświadczenie polowe założono w układzie bloków losowych w czterech powtórzeniach dla każdej kombinacji. Czynnikiem badanym były zróżnicowane dawki fosforu i potasu, przy stałym poziomie nawożenia azotem i magnezem. Plony ziarna pszenicy ozimej w latach badań były wysokie i istotnie różniły się zarówno względem obiektu kontrolnego, jak i wariantów nawożonych. Analiza korelacji między plonem ziarna a zawartością składników w liściach w fazie początku strzelania w źdźbło (BBCH 31) wykazała istotne zależności w przypadku fosforu, wapnia, magnezu, cynku i manganu. Analiza regresji dowiodła, że głównym składnikiem decydującym o plonie ziarna pszenicy była zawartość cynku w liściach w fazie BBCH31. Nawożenie mineralne w porównaniu z wariantem kontrolnym istotnie wpłynęło na zwiększenie również zawartości białka i glutenu, natomiast nie stwierdzono istotnych różnic między obiektami nawożonymi. Wykazano istotną zależność między zawartością N, P, Mg, Zn, Mn w liściach w fazie BBCH 31 a akumulacją białka i glutenu w ziarnie. Zawartość białka i glutenu w ziarnie pszenicy w największym stopniu była determinowana przez zawartość magnezu w liściach na początku strzelania w źdźbło. Czynnikiem istotnie różnicującym wyrównanie ziarniaków były warunki pogodowe, natomiast nawożenie mineralne nie miało wpływu na kształtowanie tej cechy.

Słowa kluczowe: pszenica ozima, dawki potasu i fosforu, gluten, białko, wyrównanie ziarna.

# INTRODUCTION

Achievement of the basic goal of fertilization, which is high, stable and good quality yields, requires that phosphorous and potassium should not demonstrate their suppressing effects at any of the plant development stages. Among the nutrients which affect grain quality, nitrogen is most often indicated (EHDAIE, WAINES 2001, SHI et al. 2010). Doubtless, application of higher nitrogen rates results in higher yields, although technological parameters of such yields still raise controversies. Besides stimulating yields, high rates of nitrogen can cause worse quality of gluten in grain by increasing the share of low-molecular gliadin (WOODING et al. 2000). For the sake of attaining the producer's and the processor's economic and technological targets, it is important to elaborate such mineral fertilization rates that allow plants to produce high yield, close to the crop's yielding maximum capacity, with good quality characteristics. The risk of yield decline can be minimized by application of mineral fertilization balanced in terms of all nutrient elements (ÖBORN et al. 2005). The influence of phosphorus and potassium is mainly an aggregate of the functions played by nutrients in mitigating negative effects of biotic and abiotic stresses. Plants provided with sufficient amounts of phosphorus and potassium are less vulnerable to water deficiency, low temperatures and pathogen attacks (MA et al. 2006). Potassium and phosphorus yield-stimulating functions are different, which stems from their differentiated influence on the plant growth during the vegetation period. These two mineral elements together shape nitrogen management in high-yield cultivation technologies (MARSCHNER 1986). Potassium is an indispensable component during the main stages of protein biosynthesis. Its deficiency leads to a decrease of protein amount produced by a plant, and this effect occurs regardless of the nitrogen nutrition level and accumulation of non-protein nitrogen, the presence of which fosters fungal infections (RICE 2007). Furthermore, potassium deficiency impedes nitrogen uptake and, as a result, the growth of leaf assimilation surface; it also reduces the uptake and transport of nitrates in plants (MARSCHNER et al. 1996). Many researchers have undertaken to evaluate effects of P and K rates on plant yields, but until now information on yield quality traits has been scarce. Relevant literature lacks consistent data concerning the influence of a phosphorus-potassium fertilization level on the technological value of bread wheat cultivated on sites rich in P and K. In this study, a hypothesis was made that differentiated fertilization with P and K before sowing would influence bread wheat yield along with the content of protein and gluten.

The aim of the field study was to evaluate the response of winter wheat in terms of yield volume and quality to optimal and reduced rates of potassium and phosphorus fertilization.

## MATERIAL AND METHODS

The study was carried out in 2007-2010, on a farm in Wieszczyczyna, a village near the town of Śrem, Poland, 52°02' N 17°05'E. The research was based on a one-factor experiment conducted on cv. Kris winter wheat. This wheat cultivar belongs to class B of bread wheat varieties. The experiment was part of a long-term research project started in 2000. The trials were set up in a randomized-block design with four replications. The experimental factor was differentiated mineral fertilization with phosphorus and potassium. The experiment was carried out on lessive soil, developed from loam, and lying shallow on glacial till. The soil used in the study was classified as representing quality class IIIb in the Polish soil valuation system. It was rich in available phosphorus (92 mg P kg$^{-1}$ of soil), but the content of available potassium ranged from medium to low (120-80 mg K kg$^{-1}$) and that of magnesium was medium (37 mg Mg kg$^{-1}$). The soil reaction was slightly acidic (pH 5.94 1M KCl). Every year, winter wheat was grown after maize. All crop cultivation practices were carried out according to the optimal ones under given agronomic conditions. Taking into account the soil fertility, unit uptake and expected yield of 7 t ha$^{-1}$ during the whole study, an optimal mineral fertilization level (W100) was determined. Every year, the phosphorus rate was 35 kg $ha^{-1}$, and the potassium dose was 100 kg $ha^{-1}$ in treatment W100, except in 2007, when the K fertilization level was higher (133 kg K $ha^{-1}$). Determination of the optimal rate (W100) was performed with the use of NawSald software (IUNG, Puławy, Poland). Based on phosphorus and potassium fertilization levels, which were balanced with regard to nitrogen, the other tested P and K rates were determined by reducing P and K fertilization down to 25% (W25) and 50% (W50) of the optimum balanced treatment (W100). Additionally, control variants were established, where either phosphorus (WKN) or potassium (WPN) was not applied and constant levels of nitrogen and magnesium were maintained. In accordance with the experimental design, fertilization with phosphorus, potassium and magnesium was carried out at the same rate after harvesting preceding crops. Potassium was applied as potassium chloride salt (60% $K_2O$), phosphorus as single superphosphate and magnesium as kieserite (27% MgO). In the WP1 treatment, phosphorus was applied as Partially Acidulated Phosphate Rock. The WP1 treatment was considered an alternative to single superphosphate as a source of phosphorus. Rock phosphate was also used. It contained 10.2% of phosphorus and its acidification was 50% (i.e. the amount of sulphuric acid used up during the technological processing to obtain the end product was 50% of the amount necessary for production of single superphosphate). Fertilization with nitrogen as ammonium nitrate at a total rate 180 kg N $ha^{-1}$ was carried out four times and divided as specified: (I) before autumn sowing 30 kg (kg N $ha^{-1}$); (II) before the onset of spring growth 60 kg N $ha^{-1}$; (III) 3 weeks after application of the second N dose 30 kg N $ha^{-1}$, and (IV) at the beginning of the earing stage 30 kg N $ha^{-1}$.

At the beginning of the stem elongation stage (BBCH-31), plants were sampled from all experimental plots for chemical analyses (from 1 linear metre). Plants collected with a harvester from an area of 20 $m^2$ were used for assessments of grain yield. The plant material was prepared as required for determination of the nutrient content (with atomic absorption spectroscopy) and the following parameters were determined: total protein content (%N x 5.75 – Kjeldahl's method, PN-75A-04018), gluten content (in an Infraanalyser 500) and grain uniformity (standards by the Agency of Agricultural Market).

The results were statistically analyzed with one-factor ANOVA. The years of the experiment were regarded as a random factor and the PK fertilization level was a fixed factor. Multiple regression analysis with choice of the best subset of variables was applied for evaluation of cause and effect relationships between the parameters analyzed. The statistical analyses were performed with the use of Statistica© 10 software.

## RESULTS AND DISCUSSION

### Grain yield

During the whole experiment, the wheat grain yields were high compared to average winter wheat crops achieved in the last ten years in Poland. The average wheat grain yield obtained from the fertilized treatments was 6.6 t $ha^{-1}$, 32% higher than from the control (Figure 1). Although the tested wheat cultivar showed a weak response in yield to increasing P and K rates, this did not mean that its nutrient requirements were low, especially in view of the nutrient uptake (data can be provided by the authors). Wheat responded to a 10-year-long absence of phosphorus and potassium fertilization by a slight yield decrease. Bigger yield appeared in the treatment without phosphorous fertilization (WKN) than without potassium application (WPN). Batten et al. (1984) found that high-yield winter wheat varieties had high requirements with regard to phosphorus, hence this plant should be cultivated on soils rich in phosphorus or else adequately supplemented with high rates of this element. The lack of response of yields produced by wheat as well as other plants to pre-sowing fertilization with phosphorus has been confirmed elsewhere (Gaj 2008, 2010, Rose et al. 2008). Reports on long-term fertilization with phosphorus indicate that a decrease of yield due to absence of phosphorus fertilization becomes demonstrable after longer time (Moskal et. al. 1999, Stępień, Mercik 1999, Kunzova, Hejcman 2010). Potassium is rarely referred to in the world's literature as an element limiting plant production, although it is most often pointed out as the main nutrient shaping the quality of products (Usherwood 1985, Whitehead 2000).

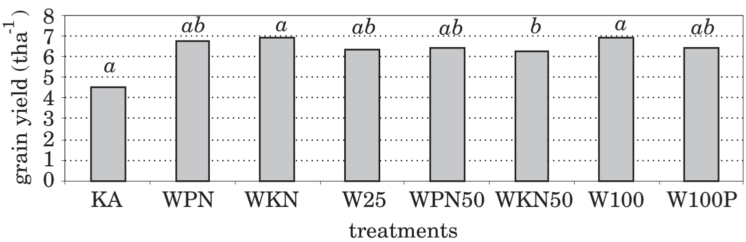


Fig. 1 Yield of grain winter wheat according to phosphorus and potassium fertilization
*a,b,c* – letters indicate statistical differences between treatments, $p < 0.05$

Wheat grain yield significantly depended on plant nutrition at the beginning of stem elongation stage (BBCH 31) – Table 1. Regression analysis showed significant positive influence of leaf content of nitrogen, potassium, magnesium and zinc on wheat grain yield (equation 1). Negative relationship was observed only in the case of copper. The level of plant nutrition with phosphorous, calcium, manganese and iron at that plant development phase had no considerable effect on grain yield.

Table 1

Correlation coefficients between yield of winter wheat, quality parameters and nutrients content in critical state ($n$=128)

| Variable | Nutrient | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | Mg | Ca | Zn | Cu | Mn | Fe |
| Yield | 0.11 | 0.221* | 0.165 | 0.335* | -0.220* | 0.458* | -0.16 | 0.363* | 0.203* |
| Gluten content | 0.211* | 0.335* | -0.07 | 0.379* | -0.08 | -0.217* | 0.264* | 0.216* | 0.289* |
| Protein content | 0.238* | 0.253* | -0.01 | 0.283* | -0.07 | -0.176* | 0.132 | 0.241* | 0.307 |
| Grain uniformity | 0.085 | -0.433* | 0.289* | -0.492* | 0.303* | 0.266* | -0.183* | -0.209* | -0.301* |

*correlation significant at $p < 0.05$

$$(1)\ Y(t\ ha^{-1}) = 0.12(Zn) + 6.64(Mg) + 0.43(N) + 0.77(K) - 0.57(Cu) + 1.65$$

$$R^2 = 0.49;\ n = 128;\ p < 0.000$$

Zinc content in winter wheat leaves at the beginning of stem elongation stage determined wheat grain yield, and explained 36.4% of the variability (equation 2).

$$(2)\ Y(t\ ha^{-1}) = 0.195(Zn) + 2.88 \qquad R^2 = 36.4\%;\ n = 128;\ p < 0.000$$

The increase in the zinc content in plants at the beginning of stem elongation by 1 mg $kg^{-1}$ resulted in an increase in the wheat grain yield by an average 195 kg $ha^{-1}$.

Statistically significant interaction between the experimental factor and years of observations was found. Most advantageous weather conditions for wheat yielding were observed in 2009, whereas the lowest wheat yields were obtained in 2008. The difference in yields between the extreme years was 33%. The irregular distribution of precipitations in the months when the most intensive plant growth takes place (April, May and June) was the main reason for limited nutrient uptake from soil and, consequently, the observed yield reduction.

**Evaluation of grain quality**

The qualitative cereal analysis comprised three features: protein content, gluten content and grain size uniformity. The amount and quality of protein substances are two of the main criteria of wheat technological usefulness. The winter wheat variety tested in this study, cv. Kris, belongs to the quality group B, which means that its genetically conditioned parameters such as protein or gluten content are on a medium level (between quality wheat and forage wheat) (Gacek 2002). Regardless of the year of observation, treatment-specific differences in the analyzed parameters were mainly demonstrated by the significance of the comparison of the absolute control treatment (no NPK fertilization) with the other treatments (Table 2).

Table 2

Effect of phosphorus and potassium fertilization on technological quality grain of winter wheat

| Factors | | Feature | | |
|---|---|---|---|---|
| | | gluten content (%) | protein (%) | grain uniformity (%) |
| Years | 2007 | 21.95*d* | 10.94*c* | 88.91*a* |
| | 2008 | 28.84*a* | 13.10*a* | 56.66*d* |
| | 2009 | 24.33*c* | 11.77*b* | 74.48*b* |
| | 2010 | 25.58*b* | 12.10*b* | 64.69*c* |
| Treatments | control (KA) | 19.86*b* | 10.17*b* | 78.32*a* |
| | WNK | 26.24*a* | 12.38*a* | 70.08*a* |
| | WNP | 26.14*a* | 12.33*a* | 71.44*a* |
| | W25 | 25.74*a* | 12.01*a* | 67.58*a* |
| | WPN50 | 25.62*a* | 12.11*a* | 72.94*a* |
| | WKN50 | 26.36*a* | 12.39*a* | 67.69*a* |
| | W100 | 25.59*a* | 1203*a* | 70.90*a* |
| | W100P (P as PAPR) | 25.84*a* | 12.23*a* | 72.53*a* |
| Interaction: year×treatments | | * | * | * |

* signifficantly different;
*a,b,c*, - letters indicate statistical differences between treatments, $p < 0.05$

Differentiation of P and K rates had no significant influence on protein and gluten accumulation in grain. The content of gluten indicated a proven linear relationship with the total protein content (Figure 2). Relationships between the total grain protein content and the grain content of gluten are very complex and largely determined by the variety (GRZEBISZ, GAJ 2009). The content of gluten observed in this study was at the threshold level for bread winter wheat (26%), which corresponds to at least 12.0% accumulation of protein in grain, The content of protein in the control variant was lower than the standard value, and equalled 10.2%. Fertilization is one of the main factors which determine both the volume of wheat yields and the amount of protein and gluten in wheat grain (FLYNN et al. 1987, SHEWRY et al. 1995). The results of GALANTINI et al. (2000) indicated that fertilization did not increase dry matter, but significantly influenced nutrient accumulation in grain. The results of the present study showed that increasing phosphorus rates had no direct effect on raising the content of protein and gluten in grain, whereas within the locations which had not been fertilized with phosphorus (treatment WNK) or potassium (treatment WNP) for ten years,

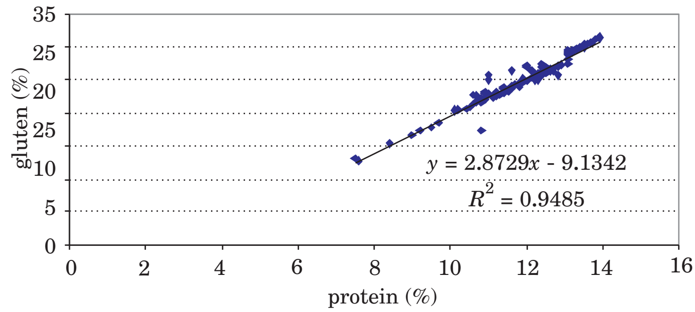


Fig. 2. Gluten content in grain as function of protein content

a tendency was observed for a slight increase in values of the analyzed parameters when compared to the variant with an optimum nitrogen balance (W100). Dick et al. (1985) reported a protein content decrease in barley grain under influence of potassium fertilization. The effect of potassium on the quality traits of plant products is revealed indirectly, through activation of certain enzymes responsible for basic and specific metabolic processes in plants (Szczepaniak 2004). The effect of phosphorus on the content of protein in grains has not been defined unambiguously in literature, hence the issue remains problematic. Available information concerns the volume of yield rather than its quality. It is generally believed, however, that phosphorus slightly affects grain proteins in winter wheat (Cambell 1996, Batten et al. 1999, 1992, Benbella, Paulsen et al. 1998). During the present study, no differences were observed in the analyzed parameters with regard to the form of phosphorus fertilizer applied. The content of protein in grain is directly connected with the overall available nitrogen, both from mineral fertilizers and from mineralization processes in soil. Besides, the wheat grain protein content is strongly connected to temperature, especially at the phase of grain filling (Podolska, Sułek 2003, Budzyński et al. 2004, Shi et al. 2010).

Quality parameters, such as protein and gluten content as well as grain size uniformity, were strongly influenced by the weather conditions. The ANOVA test showed statistical significance of the interaction between the year and the rate of PK fertilization in determination of the tested parameters (Table 2). An average protein content in the fertilized treatments fluctuated within a very narrow range from 12.01 to 12.4. Olson (1984) emphasized that the factors which increased grain yield often caused a decrease of protein content, since yield increase resulted in the dilution effect. According to this author, additional phosphorus or moderate rates of nitrogen can counteract such processes. Berecz (2001) pointed out that the influence of phosphorus fertilization on wheat quality parameters depended largely on the N:P ratio. The issue of interaction between nitrogen and phosphorus is referred to in many publications (Summer, Farina 1986, Kim 2003, Prystupa et al. 2004, Sadras 2006].

The highest amounts of gluten and protein in wheat grain were observed in 2008, which was characterized by low precipitation and high temperature (Table 3). Wheat plants produced relatively less vegetation matter under water stress caused by drought and therefore a larger pool of nitrogen was accumulated in grain. High temperature causes fast hydrolysis of leaf proteins so that the stage of grain filing lasts shorter, which generates lower weight of grain but high grain protein content (Corbellini et al. 1998, Daniel, Triboi 2002, Flagella et al. 2010). Also, Hajheidari et al. (2007) observed an increase in the content of gliadins in bread wheat varieties under water stress consistently with an increase in protein content. According to Triboď et al. (2003), differences in the composition of the protein fraction at plant maturity due to post-anthesis temperatures or drought after the flowering phase, and are primarily caused by differences in the amount of nitrogen accumulated during the grain filling phase. occurs mainly because of differences in the total quality of nitrogen accumulated during grain filling.

Another feature assessed was grain size uniformity. Differentiation of mineral fertilization had no significant effect on variability of this feature, although the effect of weather conditions (Table 2) is noteworthy. In 2008 and 2010, grain uniformity observed on all treatments was below the standard value (< 75%). Poor grain uniformity indicates high sensitivity of the tested wheat variety to weather conditions at the stage of grain filling. Although the quality standards for the content of protein and gluten (the Agency of Agricultural Market norms) were met, poor grain uniformity in 2008 and 2010 disqualified the grain yield for milling.

Table 3

Weather conditions during vegetation of winter wheat

| Vegetation season | Months | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aug | Sept | Oct | Nov | Dec | Jan | Feb | March | Apr | May | June | July |
| Temperature (°C) | | | | | | | | | | | | |
| 2006/2007 | 18.1 | 17.1 | 11.1 | 6.6 | 4.5 | 4.6 | 0.9 | 6.1 | 10.1 | 15.2 | 19.2 | 18.7 |
| 2007/2008 | 18.7 | 13.1 | 7.9 | 2.6 | 1.1 | 2.0 | 4.0 | 4.1 | 8.5 | 14.2 | 18.7 | 19.8 |
| 2008/2009 | 18.6 | 13.1 | 9.0 | 5.5 | 1.1 | -3.3 | -0.3 | 3.8 | 11.1 | 13.4 | 15.9 | 19.6 |
| 2009/2010 | 19.1 | 14.7 | 7.3 | 6.2 | -1.0 | -7.0 | -1.7 | 3.6 | 8.9 | 12.3 | 17.6 | 21.9 |
| Multi-year | 17 | 13.1 | 8.3 | 3.2 | 0.4 | -1.2 | -0.4 | 3.2 | 7.8 | 13.6 | 16.6 | 18.3 |
| Precipitation (mm) | | | | | | | | | | | | |
| 2006/2007 | 148 | 23 | 35 | 47 | 42 | 86 | 49 | 50 | 6 | 78 | 66 | 112 |
| 2007/2008 | 48 | 23 | 15 | 34 | 26 | 65 | 41 | 44 | 5 | 42 | 48 | 126 |
| 2008/2009 | 48 | 23 | 15 | 34 | 26 | 72 | 23 | 34 | 38 | 17 | 12 | 46 |
| 2009/2010 | 62 | 16 | 61 | 18 | 20 | 25 | 49 | 56 | 19 | 69 | 101 | 86 |
| Mult-year | 64 | 45 | 40 | 42 | 36 | 30 | 39 | 36 | 51 | 62 | 74 | 64 |

**Plant nutrition and yield quality**

According to Grzebisz et al. (2003), the basic question in discussions on the effect of fertilization on agricultural produce quality is the assessment of reactions between the plant nutritional status and the quality of plant products. Regression analysis on the relationship between leaf nutrient contents at the BBCH31 stage (in literature referred to as the critical phase; Bergmann, 1992) and the content of protein (equation 3) and gluten (equation 4) in wheat grain showed positive relationships for nitrogen, magnesium, phosphorus and iron, but negative one for zinc. The equations supported the presumed hypothesis on the effect of phosphorus on grain qaulity.

$$(3)\ Y = 0.67N + 6.62Mg + 4.67P + 0.01Fe - 0.10Zn + 7.75$$

$$R^2 = 0.46;\ n = 128;\ p < 0.000$$

$$(4)\ Y = 2.10N + 20.30Mg + 14.73P + 0.03Fe - 0.35Zn + 13.05$$

$$R^2 = 0.48;\ n = 128;\ p < 0.000$$

The stepwise multiple regression analysis with backward elimination and choice of best variable sub-sets showed that protein and gluten content in grain was determined most strongly by the content of magnesium (equations 5 and 6).

$$(5)\ Y(\%\ \text{protein}) = 6.50(Mg) + 10.90 \quad R^2 = 15.41\%;\ n = 128;\ p < 0.000$$

$$(6)\ Y(\%\ \text{gluten}) = 19.15(Mg) + 22.08 \quad R^2 = 14.74\%;\ n = 128;\ p < 0.000$$

The plant nutritional status at the BBCH31 stage significantly influenced grain size uniformity (Table 1). Regression analysis showed significant positive relationship only for zinc (equation 7).

$$(7)\ Y = 1.44Zn - 122.8Mg - 5.73Cu - 0.09Cu + 99.18$$

$$R^2 = 55.08\%;\ n = 128;\ p < 0.000$$

## CONCLUSIONS

1. On soils rich in phosphorus and potassium, winter wheat yielding response to different P and K rates was significantly differentiated, which implies that this crop has high demand for nutrient-rich soils.

2. Mineral fertilization significantly increased the protein and gluten content in grain only in comparison with the control, and the differentiation of P and K rates had no effect on the differences between the treatments.

3. Significant relationship was found between the plant nutritional status at the beginning of stem elongation phase (BBCH 31) and bread wheat

quality. Regression analysis showed that the protein and gluten content were most strongly dependent on the content of magnesium in wheat leaves at this plant development stage.

4. Weather conditions constituted a factor which significantly differentiated grain size uniformity, while mineral fertilization had no influence on this feature.

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