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CONTENT OF MACRONUTRIENTS OF MALTING BARLEY IN DEPENDENCE OF NITROGEN NUTRITION LEVEL

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Abstract

*Macronutrients content of five barley varieties was studied at three levels of nitrogen 0, 200, and 400 mg N/kg soil. It was found that the Kristi variety had a low grain protein content of 8.8% on average. Obzor, Krami and Kaskadior varieties increased the crude protein in the grain to 12.3-13.0% at the N_{400} level. Strong positive correlation was proven between the soil nitrogen and grain protein (r=0.993**). Added nitrogen (N_{400}) increased the straw nitrogen content from 0.51% N_0 to 0.74% N. The Krami variety showed a higher concentration of grain phosphorus 0.87% P_2O_5, on average. The grain potassium content slightly depended on the variety. Varieties grown at N_{400} level had a higher concentration of potassium at maturity and of phosphorus in the grain than the plants at N_0. Calcium content of grain was higher in Emon and Kristi varieties (0.30 and 0.29% CaO, respectively), and in straw in Kristi and Kaskadior (1.10 and 1.14% CaO, respectively). Nitrogen level had a little effect on the calcium and magnesium contents. Their average concentrations of barley grain were 0.28% CaO and 0.12% MgO at N_{400} variant.*

***Key words**: mineral composition, malting barley, nitrogen.*

INTRODUCTION

Barley is the main source of raw material for the brewing industry as well as for feeding animals. Its intensive cultivation is due to high-yielding varieties, possessing high ecological plasticity and yield stability. The genotypic specificity of mineral nutrition is a complex problem and depends on a number of interacting factors (Rogers et al., 2022). The main task is the creation of varieties with high efficiency in the use of both natural soil fertility and mineral fertilizers. In this way, the obtaining of sustainably high, qualitative and economical yields is ensured. Genetic specificity in mineral nutrition is judged by responsiveness to the level of fertilization, and one of the main indicators of research is the content of nutritional elements in the grain and straw of barley (Below, 1995).

Higher yields of modern barley varieties have been found under a wide range of nitrogen fertilization (Abeledo et al., 2003a). Despite significant genetic improvements in grain yield, their impact on grain mineral content may be different. Regarding grain nitrogen, it is important how the selection process has affected the balance of utilization of the two elements nitrogen and carbon in plants (Acuñaet al., 2005; Rogers et al., 2019). Quality barley for malting industry should contain more than 60% of starch and less than 12% of total proteins (Popovich et al., 2011). The effect of nitrogen level on barley characteristics depends on applied nitrogen rates and climate characteristics during the growing period. Sample nitrogen rates of 80 to 120 kg N/ha are most often indicated for malting barley (Koteva, 2001). High nitrogen rates increase the productivity of barley and, in parallel, the crude protein content increases, which, above certain limits, adversely affects its brewing-technological qualities (Rogers et al., 2022; Peev and Krasteva, 1989).

A number of factors influence the total nitrogen in the barley grain, respectively the crude protein. During grain filling, nitrogen is redistributed from the vegetative parts to the grain. Roots remained active during the grain filling, in which high mobile nitrogen content in the soil at the end of the growing season could account for a higher percentage of nitrogen in the grain. Barley can absorb up to 35 kg N/ha from the soil after flowering (Gastal & Lemaire, 2002). High nitrogen content in the grain may be due to a high input of nitrogen to the grain late in the growing season. This gain may be the result of soil uptake, enhanced reutilization by vegetative parts, or poor plant carbohydrate stores (Abeledo et al., 2008). Other causes of high nitrogen content in the barley grain are drought, lodging, disease, all of which reduce yield without affecting the redistribution of nitrogen to the grain (Stevens et al., 2015). The effect of barley fertilization can influence in a different direction from the purpose of selection. Research on grain nitrogen concentration in new barley genotypes is necessary for breeding technology, brewing industry and future selection. Cultivars must maintain grain nitrogen at appropriate values for beer production so that changes in plant nitrogen status are narrower than carbon for a stable NHI/GHI ratio (Lawlor, 2002). The chemical composition of barley depends on the variety and the level of mineral nutrition, and on the specifics of the course of phenological phases (Verma et al., 2003).

The aim of the present study was to investigate the effect of the level of nitrogen nutrition on the content of the macronutrients nitrogen, phosphorus, potassium, calcium and magnesium in the grain and straw of Bulgarian varieties of malting barley.

MATERIALS AND METHODS

Five Bulgarian varieties of malting barley, registered in the Official Varietal List of the country, well known and used in the country, were included in the present study. Obzor and Emon are long-standing standards for winter double-row barley, created at the Institute of Agriculture - Karnobat. They have a distinct winter-spring type of development, medium-tall stems with medium-thick, spiky spikes. Krami and Krispi varieties were selected at the Agricultural University of Plovdiv. They have very good brewing technological qualities and are suitable for cultivation in the dry regions of the country, especially southern Bulgaria (Lukipudis, 2008). Stems are lower, with shorter spikes. These two varieties are characterized by high productivity due to better productive tillering. The Kaskadyor variety is part of the selection achievements of the Agricultural Institute. It is distinguished by a taller stem and long spikes, as well as good productivity under the conditions of Northern Bulgaria.

The plants were grown in plastic containers with a volume of 5 L (10 plants per container). The barley varieties were studied at three levels of nitrogen nutrition: 0, 200 and 400 mg N/kg soil. Each variant was run in four replicates. The nitrogen levels were created by NH_4NO_3 fertilization. The soil used has pH water = 7.2 and contains mineral nitrogen 43.7 mg N/kg, mobile phosphorus (Egner-Riem) and absorbable potassium (2N HCl) 20.9 and 45 mg/100 g, respectively.

Barley grain and straw were analyzed at maturity. The plants were previously dried at 60°C to constant weight and weighed. The dry plant samples were ground and an aliquot part of them was mineralized with concentrated sulfuric acid under a hydrogen peroxide catalyst, after which the content of total nitrogen, phosphorus (colorimetrically on a spectrophotometer model Camspec M105) and potassium (on a flame photometer model PFP-7) was determined.

The calcium and magnesium content of barley grain and straw was determined in concentrated hydrochloric and nitric acids (ratio 3: 1) on an AAS model Perkin-Elmer 200 Analyst after microwave mineralization on a Milestone 2000 mega furnace. The crude protein content of the barley grain was calculated from the percent of nitrogen content multiplied by a factor of 5.7 (N% x 5.7).

Analysis of variance (ANOVA) for two-factor experiments and Duncan's (1955) multivariate comparison test were used for mathematical processing of the obtained results. Only differences at α=0.95 were accepted as proven.

RESULTS AND DISCUSSIONS

An improvement in barley productivity is associated with a decrease in nitrogen concentration in the grain (Abeledo et al., 2003b). The percentage of grain nitrogen depends on the genotype (Cox et al., 1985; Emebiri & Moody, 2004; Przulij & Momcilovic, 2001), growing conditions during the vegetation period (Boonchoo et al., 1998; Paynter & Young, 2004) and their interaction (Bertholdsson, 1999). Crude protein content of the barley grain is only one of the characteristics related to malting quality, but it is the most important indicator for the brewing industry, varying between 8.5% and 12.5% (Gali & Brown, 2000). In England, malting barley varieties are used for beer production if 70% of the production contains total grain nitrogen within the range of 1.55% to 1.85% or 8.8% to 10.5% expressed as crude protein (Collen, 2006).

Table 1. Crude protein concentration of barley grain, %

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	8.6ab*	10.2a	12.3ab	10.4ns***
Emon	8.3b	10.7a	11.9b	10.3
Krami	7.9bc	9.3b	12.5a	9.9
Kristi	7.5c	8.9b	10.1c	8.8
Kaskadior	9.1a	10.2a	13.0a	10.8
Average N level	8.3C**	9.9B	12.0A	

*Values in each column followed by the same lowercase letters are not significantly different at $p<0.05$
**Values in the row followed by the same uppercase letters are not significantly different at $p<0.05$
***Not significantly different at $p<0.05$

The average content of crude protein in the grain of the five Bulgarian varieties grown at three levels of nitrogen was 10.1% (Table 1). It varied within the limits of 7.5% (Kristi variety at N0) to 13% (Kaskadior variety at N_{400}). Our results confirmed that nitrogen fertilization increased the crude protein content of the grain. This indicator increased from 8.3% on average for unfertilized plants to 12.0% for varieties fertilized with 400 mg N/kg soil. The Kristi variety was characterized by a low content of crude protein in the grain. This was found at all three nitrogen levels. Varietal response averaged over the three nitrogen levels was unproven. Increased nitrogen fertilization N_{400} leaded to high values of grain protein concentrations (12.3-13.0%) of Obzor, Krami and Kaskadior varieties and it reduced the quality of grain for beer production. Strong positive correlation was found between the level of nitrogen nutrition and the percentage of crude protein in the grain (r=0.993**).

Table 2. Nitrogen concentration of the barley straw, (N %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.49b	0.57ns	0.72ab	0.59ns
Emon	0.53ab	0.58	0.74ab	0.62
Krami	0.57a	0.64	0.79ab	0.67
Kristi	0.43b	0.55	0.63b	0.54
Kaskadior	0.55a	0.68	0.83a	0.69
Average N level	0.51C	0.60B	0.74A	

The average concentration of nitrogen in the straw of the studied barley varieties increased in parallel with the level of nitrogen nutrition from 0.51% at the N_0 to 0.74% at the N_{400} level (Table 2). The content of nitrogen in the straw was the lowest in Kristi variety 0.43% at N_0 and the highest in Kaskadior variety grown at N_{400} level. The differences in the concentration of nitrogen in the straw depending on the variety of the plants grown at the N_{400}, as well as in the average of the three nitrogen levels, were insignificant.

Table 3. Phosphorus grain concentration of barley, (P_2O_5%)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.72ab	0.77b	0.84a	0.78ab
Emon	0.67b	0.73b	0.79b	0.73b
Krami	0.81a	0.87a	0.92a	0.87a
Kristi	0.69b	0.76b	0.82ab	0.76ab
Kaskadior	0.63b	0.70b	0.75b	0.69b
Average N level	0.70B	0.77aAB	0.82A	

The average content of phosphorus in the grain of the studied barley varieties grown at nitrogen levels N_0, N_{200} and N_{400} was 0.76% P_2O_5 (Table 3). It changed from 0.63% P_2O_5 in unfertilized plants of the Kaskadior variety to 0.92% P_2O_5 in the Krami variety at the N_{400} level. The level of nitrogen in the soil increased the phosphorus content of the barley grain, but proven differences were found between the level of N_{400} and the cultivars grown without nitrogen addition. The Krami variety was distinguished by a higher concentration of phosphorus in the grain at all three levels of nitrogen. Varietal response was demonstrated regardless of the level of applied nitrogen.

Table 4. Phosphorus concentrations of barley straw, (P_2O_5 %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.43ns	0.46ns	0.50ns	0.46b
Emon	0.39	0.43	0.45	0.42ab
Krami	0.47	0.50	0.53	0.50a
Kristi	0.42	0.48	0.51	0.47ab
Kaskadior	0.45	0.51	0.55	0.50a
Average N level	0.43ns	0.48	0.51	

The Krami variety was characterized by a high concentration of phosphorus in the grain (0.89% P_2O_5) compared to Emon (0.73% P_2O_5) and Kaskadior (0.69% P_2O_5) varieties.

The concentration of phosphorus in barley straw had similar values and was 0.47% P_2O_5

on average for the present experiment (Table 4). Proven varietal differences at the three levels separately were not observed. However, the average values of N_0, N_{200} and N_{400} levels indicated Obzor variety with lower grain phosphorus content compared to Krami and Kaskadior cultivars. The levels of nitrogen nutrition had little influence on the average phosphorus content of barley straw.

Table 5. Potassium grain concentrations of barley, (K_2O, %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.64ns	0.77ns	0.82ns	0.74ns
Emon	0.55	0.65	0.73	0.64
Krami	0.59	0.66	0.74	0.66
Kristi	0.62	0.69	0.75	0.69
Kaskadior	0.61	0.71	0.78	0.70
Average N level	0.60B	0.70A	0.76A	

The studied barley varieties contained an average of 0.69% K_2O in the grain (Table 5). The values of this indicator varied within relatively narrow limits from 0.55% K_2O (Emon variety at N_0) to 0.82% K_2O (Obzor variety at N_{400}). Varietal response of barley in grain potassium concentration was weak and unproven. This was observed regardless of nitrogen level. The potassium content of the barley grain increased as a result of the applied nitrogen. Unfertilized plants contained an average of 0.60% K_2O.

Table 6. Potassium concentrations of barley straw, (K_2O %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	1.24c	1.29c	1.36c	1.30b
Emon	1.33bc	1.42b	1.51b	1.42b
Krami	1.42ab	1.51ab	1.63ab	1.52a
Kristi	1.51a	1.60a	1.67a	1.59a
Kaskadior	1.47a	1.61a	1.71a	1.60a
Average N level	1.39B	1.49AB	1.58A	

Average grain potassium concentration increased with soil nitrogen level to 0.70% K_2O (N_{200}) and 0.76% K_2O (N_{400}), but the difference between the two nitrogen levels was not proven.

The content of potassium in the straw varied from 1.24% K_2O (Obzor variety at N_0) to 1.71% K_2O (Kaskadior variety at N_{400}) (Table 6). Kristi and Kaskadior varieties were characterized by higher concentrations of potassium in the straw (1.59-1.60% K_2O). Obzor variety had the lowest content 1.30% K_2O on average of the studied nitrogen levels. Straw potassium content of barley cultivars increased with nitrogen fertilization, but the difference between unfertilized plants and the N_{200} level was unproven. The cultivars grown at the N_{400} contained an average of 1.58% K_2O in the straw, which was 13.7% higher than that of the unfertilized plants.

Table 7. Calcium concentrations of barley grain, (CaO %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.21ns	0.23b	0.24ns	0.23b
Emon	0.29	0.31a	0.31	0.30a
Krami	0.25	0.26ab	0.28	0.26ab
Kristi	0.26	0.29a	0.31	0.29a
Kaskadior	0.23	0.25ab	0.27	0.25b
Average N level	0.25ns	0.27	0.28	

The level of nitrogen slightly affected the percent of calcium in the grain and straw of the barley varieties (Table 7 and Table 8).

Table 8. Calcium concentrations of barley straw, (CaO %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.79c	0.81b	0.85b	0.82d
Emon	0.87c	0.88b	0.93ab	0.89c
Krami	0.99b	1.02ab	1.05a	1.02b
Kristi	1.05b	1.11a	1.13a	1.10a
Kaskadior	1.18a	1.11a	1.14a	1.14a
Average N level	0.98ns	0.99	1.02	

The average values within the trial were 0.27% CaO (grain) and 0.99% CaO (straw). The grain of Emon and Kristi varieties had proven higher concentrations of calcium (0.30-0.29% CaO on average) compared to Obzor and Kaskadior varieties. A varietal response was demonstrated with regard to calcium content of straw. Straw calcium concentration was higher (1.10-1.14% CaO) in Kristi and Kaskadior varieties. The Obzor variety was showed low average concentration of calcium in the straw of 0.82% CaO.

The effect of nitrogen level and variety on the magnesium content of barley grain and straw was weak (Table 9 and Table 10). The magnesium concentrations of barley grain were close values (0.11-0.15% MgO) and proven differences were not observed.

Table 9. Magnesium concentrations of barley grain, (MgO %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.11ns	0.12ns	0.11ns	0.11ns
Emon	0.12	0.13	0.12	0.12
Krami	0.11	0.12	0.12	0.12
Kristi	0.10	0.12	0.12	0.11
Kaskadior	0.14	0.15	0.14	0.14
Average N level	0.12ns	0.13	0.12	

Table 10. Magnesium concentrations of barley straw, (MgO %)

N level / Variety	N_0	N_{200}	N_{400}	Average variety
Obzor	0.09ns	0.11ns	0.10ns	0.10ns
Emon	0.07	0.08	0.09	0.08
Krami	0.06	0.07	0.07	0.07
Kristi	0.07	0.07	0.08	0.07
Kaskadior	0.08	0.09	0.11	0.09
Average N level	0.07ns	0.08	0.09	

The magnesium content of barley straw varies within narrow limits from 0.06% MgO (Krami variety at N_0) to 0.11% MgO (Obzor variety at N_{200} and Kaskadior variety at N_{400}).

CONCLUSIONS

Kristi variety had a low grain protein content of 8.8% on average. Obzor, Krami and Kaskadior varieties increased the crude protein in the grain to 12.3%–13.0% at the N_{400} level. Strong positive correlation was proven between the soil nitrogen and grain protein (r=0.993**). Added nitrogen (N_{400}) increased the straw nitrogen content from 0.51% (N_0) to 0.74% N. The Krami variety showed a higher concentration of grain phosphorus 0.87% P_2O_5, on average. The grain potassium content slightly depended on the variety. Varieties grown at N_{400} level had a higher potassium concentration in maturity and grain phosphorus than the plants at N_0. Calcium content of grain was higher in Emon and Kristi varieties (0.30-0.29% CaO), and in straw in Kristi and Kaskadior (1.10-1.14% CaO). Nitrogen level had a little effect on the calcium and magnesium contents. Their average concentrations of barley grain were 0.28% CaO and 0.12% MgO at N_{400}.

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