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An Increase of the Mineral Contents of Barley Grain by Genotype, Planting Time and Seed Size

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In this study, cultivars, planting time and seed size were examined as potential factors to improve mineral composition of barley grain. Ten barley genotypes of different origins were studied. Fall and spring plantings were compared using five cultivars. Four seed size groups of two cultivars were also studied. There were considerable variations for most minerals among barley cultivars and hence, choice of appropriate cultivars may result in better mineral compositions. *H. spontaneum*, a wild relative of cultivated barley, contained high amounts of Ca, Fe and Mn minerals. In general, fall planted barley had higher mineral content than spring planted barley. Seed size did not affect mineral contents of the seed except copper where smaller seeds had higher copper.

Key Words: Barley, Metals, Microwave digestion, Atomic absorption spectrometry, Feed rations.

INTRODUCTION

Barley is a crop mainly grown for its grain used as a feed and in malt production. Besides, hulless barley is increasingly being used in food industry. Barley grain mainly consists of starch and protein, and the properties of grain for these two main components are of prime importance for feed and food barley. Mineral contents of the grain, on the other hand, gain importance as the consciousness in terms of food and feed quality grows. Similarly, grains used as feed are often supplemented with external mineral sources[1] which are often of artificial origin. Farming practices and cultivar differences can make up at least some part of these deficiencies and eliminate supplements from mineral salts.

Barley is intensively used in beef cattle and constitutes about 30% and over 70% of growing and finishing beef rations, respectively[2]. Barley was regarded as a better balanced feed than corn because of its higher protein and mineral contents[3]. Barley grain should contain 0.05, and 0.01% calcium and sodium, and 60, 18, 13 and 5 ppm iron, manganese, zinc and copper, respectively for beef cattle[4]. These values are 0.06 and 0.02%, and 70, 22, 38 and 6 ppm for dairy cattle[5].

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Grain calcium, sodium, iron, manganese, zinc and copper contents of 14 barley cultivars (five two-row and nine six-row) were 0.05–0.07%, 0.01–0.02%, 55–113 ppm, 15–18 ppm, 29–41 ppm and 7–13 ppm respectively[6]. Studying 150 barley varieties for mineral composition, Rasmusson *et al.*[7] reported lowest, average and highest values for Ca as 0.02, 0.04 and 0.06% respectively. Similarly, Perby and Jensen[8] reported cultivar differences for Ca accumulation in the grain. These data show that genotype pool of cultivated barley has adequate level of variation to obtain good quality grains for human and animal consumption.

Although barley grain normally retains hulls after harvest, it is possible to remove the hull from the barley mechanically or alternatively to develop hulless barley varieties. Newman and McGuire[9] reported that covered barleys contain more calcium than hulless barley and speculated that calcium is present in barley hull.

Ca, Na, Fe, Zn, Mn and Cu concentrations were reported to be low in barley endosperm[10], which could be a result of the diluting effect due to increased starch percentage. Thus, seed weight may affect the mineral content of the seed. Seed size of the grains can be altered by plant density without affecting grain yield[11] due to a compensation effect among number of heads per area, number of seeds per spike and seed weight[12]. Mineral concentration of barley is also affected by environmental factors such as growing season[13]. These factors indicate that changing the growth conditions of barley might result in a better grain quality with elevated mineral levels.

Our aim in this study was to show that cultivar choice and some farming practices could make considerable changes in mineral contents of barley grain and thus eliminate the mineral supplements of grain feeds using artificial minerals. Such a success will result in a saving of money for mineral supplements as well as in removing the unnecessary health risks due to artificial additives.

EXPERIMENTAL

In this study, barley cultivars of different origins were used. Steptoe is a six-rowed coast type feed barley. Morex is a six-rowed Manchuria type malt barley. Harrington is a two-rowed Canadian high quality malt barley. Baronesse is a two-rowed German cultivar with high yields over a very wide range of environments. Golden Promise is a two-rowed barley extensively used in barley biotechnology studies. Tokak 157/37 is a land variety which is still a predominant cultivar in Turkey. Australia is a very early flowering experimental line. Barke is a very late flowering German cultivar. GSHO1233 is a barley genetic material and its seeds are easily separated from the hulls, *i.e.*, hulless type. *H. vulgare* ssp. *spontaneum* (Wadi Qilt) is a wild barley which can easily be crossed to cultivated barley.

Four different seed weight groups were established from the spring planted Steptoe and Morex seeds. Average 1000-seed weights of Steptoe and Morex in spring planting were 2.60 and 1.95 g, respectively. Two seed weight levels below the average and one above the average were established by selecting larger or smaller seeds within the seed lots. Thus, 2.00, 2.30, 2.60 and 2.90 g, and 1.35, 1.65, 1.95 and 2.25 g 1000-seed weight samples were prepared from Steptoe and Morex, respectively.

The samples were dried at 105°C for 24 h. Dried samples were homogenized and stored in polyethylene bottles until analysis. All reagents were of analytical reagent grade unless otherwise stated. Double deionised water was used for all dilutions. HNO_3 and H_2O_2 were of supra pure quality (Merck). A Perkin-Elmer Analyst 700 model atomic absorption spectrometer with deuterium background corrector was used in this study for the elemental analysis. All measurements were carried out in an air/acetylene flame.

Samples (1.0 g) were digested with 6 mL of HNO_3 (65%), 2 mL of H_2O_2 (30%) in microwave digestion system for 31 min and diluted to 10 mL with deionised water. A blank digest was carried out in the same way (digestion conditions for microwave system were applied as 2 min for 250 W, 2 min for 0 W, 6 min for 250 W, 5 min for 400 W, 8 min for 550 W, vent: 8 min, respectively). This procedure was preferred because of its high accuracy with respect to both time and recovery values. The recovery values were nearly quantitative (> 95%) for the above digestion method.

This investigation was conducted in 2001-02 growing period in the experimental areas of Rural Services Agricultural Research Station in Tokat province of central Turkey.

Experimental soils had a clayed-loam texture, slightly alkaline soil reaction, low or moderate organic matter content, low salt content, moderate lime, low P_2O_5 and enough K_2O (Table-1). Long term (38 years) average temperature in the growing period (November–June) of the experimental area is 8.7°C (Table-2). Average temperature of November–June barley growing period was 8.9 and total precipitation was 361.4 mm.

TABLE-1
PHYSICAL AND CHEMICAL PROPERTIES OF EXPERIMENTAL SOILS

Texture	pH	Organic matter (%)	Total salt (%)	Lime (%)	P_2O_5 (kg/da)	K_2O (kg/da)
Clayed loam	7.90	1.81	0.029	10.9	3.44	37.6

TABLE-2
PRECIPITATION AND AIR TEMPERATURE IN THE REGION DURING THE GROWTH PERIOD IN LONG TERM AND EXPERIMENTAL YEARS

Climatic factor	Period	Months								Total or average
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
Total precipitation (mm)	2001–02	73.4	50.5	45.1	20.4	29.2	68.4	16.8	57.6	361.4
	1965–03	46.7	45.9	39.5	34.7	38.2	62.4	59.5	38.6	365.5
Average temperature (°C)	2001–02	7.4	5.1	–4.5	4.1	9.3	11.1	15.6	18.8	8.9
	1965–03	6.9	–2.0	5.5	2.0	3.0	11.0	17.0	18.2	8.7

Plants were grown in 30 cm wide rows. Seeds were planted on November 14th in fall and March 20th in spring. A 75 kg P_2O_5 and 150 kg N per hectare application was made in the form of triple superphosphate and ammonium nitrate, respectively.

RESULTS AND DISCUSSION

Significant variations were observed for seed calcium contents among barley genotypes. *H. spontaneum* contained almost three times as high calcium as any other barley genotype (348.6 mg/kg, Table-3, Fig. 1). Thus, *H. spontaneum* has

TABLE-3
MINERAL COMPOSITIONS OF FALL PLANTED BARLEY CULTIVARS

Cultivars	Cu (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Ca (mg/kg)
Steptoe	4.9 ± 0.2	82.3 ± 6.5	19.9 ± 1.2	11.1 ± 0.9	35.1 ± 2.8	119.2 ± 10.2
Morex	5.1 ± 0.3	81.4 ± 4.0	21.0 ± 1.3	11.4 ± 0.6	41.9 ± 4.6	135.7 ± 11.5
Harrington	6.8 ± 0.4	79.3 ± 6.3	25.9 ± 2.3	15.0 ± 0.6	62.3 ± 5.3	121.6 ± 5.6
Baronesse	6.5 ± 0.5	79.5 ± 6.1	16.7 ± 1.4	11.0 ± 0.6	40.7 ± 1.8	94.4 ± 8.1
Golden Promise	4.2 ± 0.2	84.8 ± 4.2	16.8 ± 1.3	10.7 ± 0.7	37.8 ± 2.2	116.9 ± 6.4
Tokak	6.1 ± 0.4	88.4 ± 5.4	23.5 ± 1.0	14.4 ± 1.2	136.5 ± 11.0	107.7 ± 8.8
Australia	3.4 ± 0.2	81.8 ± 3.4	27.6 ± 2.1	15.2 ± 1.2	87.1 ± 3.4	109.2 ± 7.8
Barke	5.1 ± 0.1	83.3 ± 5.4	24.1 ± 2.4	11.3 ± 0.5	43.5 ± 3.6	82.8 ± 7.6
GSHO1233	4.8 ± 0.2	82.9 ± 5.4	30.8 ± 2.9	15.9 ± 0.8	47.2 ± 3.5	121.2 ± 7.8
H. spontaneum	2.7 ± 0.1	88.0 ± 6.3	14.1 ± 1.3	23.8 ± 1.1	132.0 ± 9.6	348.6 ± 27.6
Hull	3.5 ± 0.2	88.3 ± 7.2	30.4 ± 2.3	18.8 ± 1.3	79.9 ± 4.2	157.2 ± 12.3

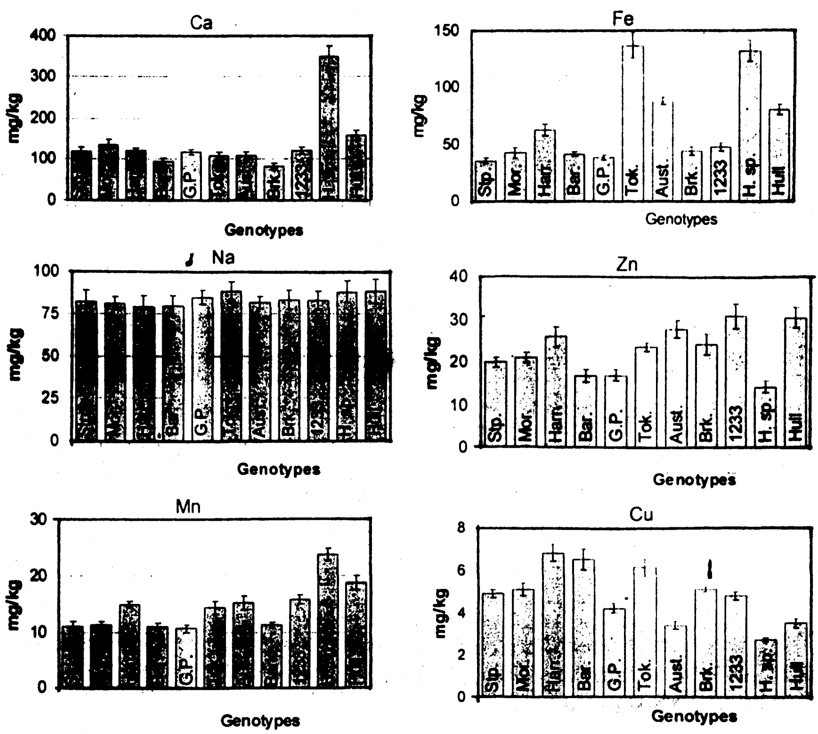

Fig. 1. Mineral compositions of fall planted barley cultivars.

a good breeding potential for calcium-rich barley improvement. Among barley cultivars, Morex had the highest (135.2 mg/kg) and Baronesse and Barke had the lowest (94.2 and 82.8 mg/kg) calcium concentrations in their seeds. Calcium contents of the hulls of GSHO1233 (157.2 mg/kg) was significantly higher than the grain (121.2 mg/kg). Based on higher calcium contents in covered barley, Newman and McGuire[9] speculated earlier that calcium in barley is present in the hull. Our findings do not support this hypothesis although calcium in hull is significantly higher than the grain. Calcium contents of seeds from all cultivars increased in fall planting. These increases were 42.9 (54.5%), 22.7 (24.0%), 19.5 (19.6%), 19.3 (16.6%) and 3.8 (4.2%) mg/kg for Harrington, Golden Promise, Steptoe, Morex and Baronesse, respectively (Table-4, Fig. 3). Thus, use of fall planted barley will result in a more balanced diet for calcium content.

TABLE-4
MINERAL COMPOSITIONS OF FIVE FALL AND SPRING PLANTED BARLEY CULTIVARS

Cultivars	Planting	Cu (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Ca (mg/kg)
Morex	Fall	5.1 ± 0.3	81.4 ± 4.0	21.0 ± 1.3	11.4 ± 0.6	41.9 ± 4.6	135.7 ± 11.5
	Spring	4.4 ± 0.5	86.0 ± 6.3	19.2 ± 1.6	10.2 ± 0.3	38.9 ± 1.7	116.4 ± 12.3
Steptoe	Fall	4.9 ± 0.2	82.3 ± 6.5	19.9 ± 1.2	11.1 ± 0.9	35.1 ± 2.8	119.2 ± 10.2
	Spring	3.0 ± 0.2	87.8 ± 2.5	19.5 ± 1.7	8.0 ± 0.4	31.6 ± 2.7	99.7 ± 8.6
Golden promise	Fall	4.2 ± 0.2	84.8 ± 4.2	16.8 ± 1.3	10.7 ± 0.7	37.8 ± 2.2	116.9 ± 6.4
	Spring	5.3 ± 0.2	88.1 ± 3.6	21.5 ± 0.9	11.4 ± 1.2	41.3 ± 3.7	94.2 ± 6.3
Baronesse	Fall	6.5 ± 0.5	79.5 ± 6.1	16.7 ± 1.4	11.0 ± 0.6	40.7 ± 1.8	94.4 ± 8.1
	Spring	6.4 ± 0.3	82.6 ± 4.2	20.8 ± 2.2	10.3 ± 0.4	42.8 ± 2.6	90.6 ± 7.3
Harrington	Fall	6.8 ± 0.4	79.3 ± 6.3	25.9 ± 2.3	15.0 ± 0.6	62.3 ± 5.3	121.6 ± 5.6
	Spring	5.4 ± 0.3	82.7 ± 7.6	19.7 ± 1.4	9.5 ± 0.3	44.8 ± 3.7	78.7 ± 7.2

Iron contents of the seeds from different cultivars showed great changes. Tokak 157/37 cultivar had almost four times as much iron content (136.5 mg/kg) as most other cultivars had, and followed by Australia (87.1 mg/kg) and Harrington (62.3 mg/kg) (Table-3, Fig. 1). *H. spontaneum* also had quite high iron content (132.0 mg/kg). Tokak 157/37 and *H. spontaneum* are genetic good sources for improvement of iron content of barley grain. Iron content of the hulls of GSHO1233 (79.9 mg/kg) was significantly higher than the grain (47.2 mg/kg)[4]. When an appropriate cultivar is used, iron will not be a problem. Iron content of fall planted Harrington seeds was 17.5 mg/kg higher (28%) in fall planting. Other cultivars had small increases or decreases for iron content in spring planting. Thus, use of fall planted barley may improve barley grain for iron mineral.

Sodium contents in the barley seed (about 80–90 mg/kg throughout the experiment) did not change among cultivars, planting times and seed sizes (Tables 3–5). However, spring planting resulted in about a 3–5 mg/kg increase in seeds of all cultivars, which makes an increase of only about 4–6%. Sodium contents of 14 barley cultivars were reported to be 150–160 mg/kg[6]. This reported narrow variation and low variation in the present study indicates that there is not much genetic variability within barley primary gene pool for sodium content in the grain.

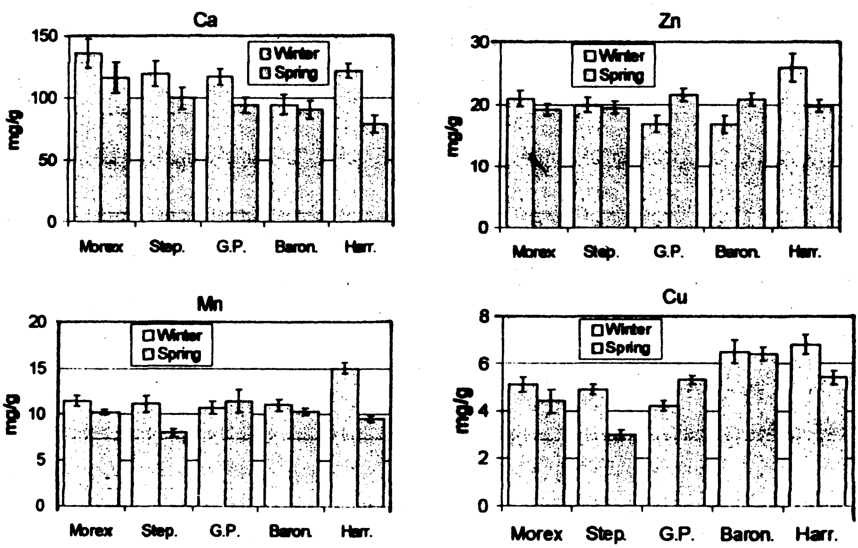

Fig. 2. Mineral compositions of five fall and spring planted barley cultivars.

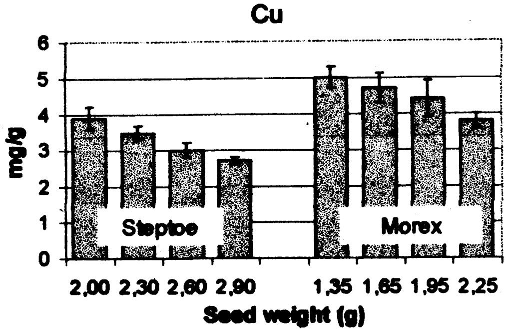

Fig. 3. Mineral compositions of four different seed size groups of two barley cultivars.

TABLE-5
MINERAL COMPOSITIONS OF FOUR DIFFERENT SEED SIZE GROUPS OF TWO BARLEY CULTIVARS

Cultivars	1000-seed weight	Cu (mg/kg)	Na (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)	Ca (mg/kg)
Morex	2.00	3.9 ± 0.3	83.2 ± 3.2	19.5 ± 1.1	10.0 ± 0.5	33.2 ± 2.4	111.3 ± 5.6
	2.30	3.5 ± 0.2	87.5 ± 3.9	20.2 ± 0.7	10.1 ± 0.4	38.7 ± 3.3	99.6 ± 4.3
	2.60	3.0 ± 0.2	87.8 ± 2.5	19.5 ± 1.7	8.0 ± 0.4	31.6 ± 2.7	99.7 ± 8.6
	2.90	2.7 ± 0.1	86.4 ± 8.2	21.8 ± 2.5	10.3 ± 0.6	29.1 ± 2.5	110.0 ± 6.5
Steptoe	1.35	5.0 ± 0.3	86.1 ± 6.1	21.4 ± 2.0	10.5 ± 1.1	41.0 ± 4.2	110.0 ± 6.4
	1.65	4.7 ± 0.4	74.1 ± 7.0	18.9 ± 1.1	9.4 ± 0.6	38.9 ± 1.7	94.9 ± 9.3
	1.95	4.4 ± 0.5	86.0 ± 6.3	19.2 ± 1.6	10.2 ± 0.3	85.4 ± 8.2	116.4 ± 12.3
	2.25	3.8 ± 0.2	86.0 ± 4.2	21.8 ± 1.3	10.0 ± 0.5	40.7 ± 2.9	112.2 ± 13.1

There were considerable differences for zinc contents of the seeds from different genotypes. GSHO1233, Australia and Harrington had the highest zinc contents (30.8, 27.6 and 25.9 mg/kg, respectively), and Baronesse and Golden Promise the lowest (16.7 and 16.8 mg/kg, respectively, Table-3, Fig. 1). Zinc content of *H. spontaneum* (14.1 mg/kg) was lower than any other genotype. These values are enough for beef cattle which needs 13 mg/kg of zinc in barley feed[4]. However, for dairy cattle which requires 38 mg/kg of zinc, choice of an appropriate cultivar might be necessary to prevent external zinc supplement in rations. Planting time resulted in different responses for zinc contents in different cultivars. Golden Promise and Baronesse had 4.7 and 4.1 mg/kg higher zinc (about 28 and 25%, respectively) in spring planting while Harrington had 6.2 mg/kg lower (about 24%). Morex and Steptoe also had 9 and 2% lower zinc contents in spring planting (Table-4, Fig. 2).

Barley cultivars had significant differences for manganese contents in their seeds. *H. spontaneum* had much higher manganese (23.8 mg/kg) in its seeds than any other barley genotype (Table-3, Fig. 1). GSHO1233, Australia, Harrington and Tokak147/37 were the cultivars with relatively high magnesium concentrations (15.9, 15.2, 15.0 and 14.4 mg/kg, respectively). Manganese content of the hulls of GSHO1233 (18.8 mg/kg) was significantly higher than the grain (15.9 mg/kg). For beef and dairy cattle, 18 and 22 mg/kg of manganese levels are required, respectively[4]. Thus, choice of cultivar becomes critical for adequate manganese mineral in barley feed. Barr *et al.*[6] reported manganese contents of 14 barley cultivars as 15–18 mg/kg which shows the narrow variability for this mineral among barley cultivars. *H. spontaneum*, which has a very high rate of manganese mineral, might be used for the improvement of barley grain for this mineral. Manganese contents of three cultivars (Morex, Steptoe and Harrington) were 1.2, 3.1 and 5.5 mg/kg higher (about 10, 28 and 35%) in fall planting while the other two cultivars (Golden Promise and Baronesse) were not affected (Table-4, Fig. 2). Thus, the use of field grown barley might improve barley feed for manganese content.

Copper contents of the cultivars varied considerably. Harrington, Baronesse and Tokak157/37 cultivars had the highest copper contents as 6.8, 6.5 and 6.1 mg/kg, respectively (Table-3, Fig. 1). Australia and Golden Promise were the cultivars with the lowest copper as 3.4 and 4.2 mg/kg, respectively. *Hordeum vulgare* ssp. *spontaneum* had lower copper contents than all other genotypes. Copper content of the grain of GSHO1233 (4.8 mg/kg) was higher than the hull (3.5 mg/kg). Barley grain should have 5 and 6 mg/kg of copper for beef and dairy cattle respectively[4]. Thus, choice of variety will result in a barley feed with enough copper mineral. Planting time affected copper content of seeds in three out of five cultivars. Fall planting resulted in 1.9 and 1.4 mg/kg more copper content in the seed of Steptoe and Harrington, respectively, while 1.1 mg/kg less in Golden Promise (Table-4, Fig. 2). Seed size had a clear diluting effect on copper content of seeds of both Steptoe and Morex cultivars (Table-5, Fig. 3). For Steptoe, copper content of seed sample which has 2.00 g of thousand seed weight was 3.9 mg/mg. Copper content of the seeds dropped almost linearly to 2.7 mg/kg for the heaviest seed weight group (thousand seed weight was 2.90 g). Such a decrease was also observed in Morex and copper content of the seeds decreased from 5.0 to 3.8 mg/kg as thousand seed weight increased from 1.35 to 2.25 g. Agronomic practices that decrease seed size without affecting grain yield such as higher planting rates[11] can improve barley grain for copper content.

In conclusion, there were considerable variations for most minerals among barley cultivars and, hence, choice of appropriate cultivars may result in improved barley feed for mineral of interest. A wild relative of cultivated barley, *H. spontaneum*, was found containing very high amounts of Ca, Fe and Mn minerals and can be used for breeding of barley cultivars with improved mineral contents. In general, fall planted barley had higher mineral content than spring planted barley although sometimes spring planted barley had higher mineral content depending upon the mineral and cultivar. Seed size did not affect mineral contents of the seed except copper where smaller seeds had higher copper contents. Thus, when the mineral content of the cultivars is taken into account along with grain yield, and when winter planting is applied, considerable amount of improvement is possible in mineral composition of feed barley, which may eliminate or at least decrease, the use of artificial mineral additives in feeds.

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