Turkish Journal of Agriculture and Forestry
http://journals.tubitak.gov.tr/agriculture/
Research Article
Turk J Agric For
(2020) 44: 46-53
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doi:10.3906/tar-1904-10

Macro- and micromineral contents of different quinoa (*Chenopodium quinoa* Willd.) varieties used as forage by cattle

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Received: 03.04.2019 • **Accepted/Published Online:** 21.06.2019 • **Final Version:** 07.02.2019

Abstract: Mineral deficiencies or mineral excess affect livestock production in most regions of the world. For this reason, it is important to know the mineral contents of forages used in animal feeding. Quinoa (*Chenopodium quinoa* Willd.), which has become a popular grain crop around the world in recent years, is used as forage in animal feeding. This study was carried out to determine the contents of macro- and microminerals and mineral balance in 9 different quinoa varieties. The results of the study indicated that mineral contents of forages show great variation between quinoa varieties. The Cherry Vanilla variety is rich in all minerals except for molybdenum. Potassium, iron, copper, zinc, manganese, molybdenum, and boron concentration in all quinoa varieties are sufficient to meet the requirements of beef cattle. In contrast, sulfur is insufficient in all varieties. The contents of phosphorus, calcium, and magnesium show deficiencies in some varieties. Although there is usually no risk of tetany (K/Ca + Mg) and milk fever (Ca/P) in quinoa forage, these mineral imbalances may be observed depending on variety.

Key words: Forage, mineral content, quinoa, varieties

1. Introduction

Quinoa (*Chenopodium quinoa* Willd.) is a traditional food crop that has been used for centuries in several South American countries. The potential of quinoa was rediscovered by the modern world during the second half of the 20th century. Its growth as an alternative plant is spreading rapidly around the world. It is highly attractive in different regions of the world for its extraordinary adaptability to extreme ecological conditions. This plant is grown in the Andes Mountains and is exposed to difficult environmental conditions, such as drought, frost, soil salinity, flooding, and heat (Jacobsen et al., 2003).

Quinoa is an ancient grain crop that is grown for its edible seeds. The most important advantage of quinoa is the high nutritional value of its seeds. Quinoa seeds are referred to as a superfood because of their high nutritional value. As quinoa seeds are used in human nutrition, its hay is also used in animal feed (Kakabouki et al., 2014). It has been used by the natives of South America since ancient times to feed ruminant and nonruminant animals. Harvest residues are also used to feed cattle, sheep, horses, and pigs. Some studies have shown that quinoa could be a valuable forage crop for dairy farms when ensiled (Podkowka et al., 2018). Moreover, there is limited data available regarding the forage quality of the quinoa crop. There are scarcely any studies on the mineral composition and mineral balance of quinoa hay. Such data are very important because of the potential use of the forage plant in animal nutrition.

There are various parameters to judge the quality of a forage crop, including crude protein, relative feed value, total digestible nutrients, and in vitro dry matter digestibility (Baskota and Islam, 2017). The mineral content of hay is one of them. Minerals are nutrients that exist in the body of ruminants and are essential for sustaining life. They are the most important factors in maintaining all physiological processes. A lack of minerals is one of the most common nutritional deficiencies. Bhargava et al. (2010) reported that the leaves of quinoa are a rich source of minerals such as calcium, potassium, and iron. Debski et al. (2013) identified the hay of quinoa as a rich source of minerals, especially zinc. The balance between minerals, as well as the mineral content of forages, are very important in animal nutrition. Tetany (hypomagnesia) and milk fever (hypocalcemia) incidences are among the most important. Therefore, it is important to know such balances in the forages of animal feed.

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There are hundreds of varieties and ecotypes of quinoa cultivated around the world. The nutrient composition of the plants may vary according to genotypes (Baskota and Islam, 2017). Therefore, it is important to determine the nutritional composition of the different genotypes. The objective of this study was to determine the mineral contents of hay in different quinoa genotypes.

2. Materials and methods

In this study, hay samples of 9 quinoa varieties obtained from different sources were used. Six of these varieties (Rainbow, Red Head, Cherry Vanilla, French Vanilla, Mint Vanilla, and Oro de Valle) were sourced from the USA. Other varieties (Titicaca, Sandoval Mix, and Moqu Arrochilla) were obtained from Denmark, England, and Peru. The varieties used in the experiment are seed types and can be used to produce forage. Forage samples were obtained from the varieties grown at the Atatürk University Agricultural Faculty Application and Research Farm in 2015. The experiment was established on clay-loamy soil with a pH of 7.1; available phosphorus was moderate, available potassium was rich, and organic matter content was low: 74 kg ha^{-1} P_2O_5, 1380 kg ha^{-1} K_2O, and 1.4%, respectively. The climate conditions of Erzurum are best characterized by low humidity and dry summers; cold and snowy winters. The total annual rainfall, average monthly temperature, and average humidity in Erzurum province in 2015 were recorded at 433.5 mm, 7.4 °C, and 77.7%, respectively.

A field experiment was established on May 5th, 2015. During sowing, 2.5–3 kg ha^{-1} of seeds were spread by hand with 35 cm row spacing at 1.5–2 cm sowing depth (Geren et al., 2015). Nitrogen fertilizer [$(NH_4)_2SO_4$] was applied at 150 kg N ha^{-1} and phosphorus fertilizer [$Ca(H_2PO_4)_2.H_2O$] at 80 kg P_2O_5 ha^{-1} (Jacobsen et al., 1994; Geren, 2015). The phenology of the varieties showed little differences, and time to flowering ranged from 56 days (Moqu Arrochilla) to 60 days (Sandoval Mix). The plants were harvested when the panicles formed and at the stage when the flowers started to open (Uke et al., 2017). Harvested plants were washed with deionized water, dried for 48 h at 70 °C, and ground to pass through a 1-mm mesh screen. The macro- and micromineral analyses were performed according to AOAC (1990) and Mertens (2005). The elements were determined after wet digestion of the dried and ground samples using an H_2SO_4:$HClO_4$ acid mixture (4:1 v/v). The phosphorus in the extraction solution was measured spectrophotometrically using indophenol-blue and ascorbic acid methods. Potassium, Mg, Ca, S, Fe, Zn, Mn, Cu, and Mo analyses were determined by atomic absorption spectrometry using Perkin-Elmer 3690. Boron analysis was done using the azomethine-H extraction method by spectrophotometer.

Macro- and microminerals were evaluated according to NRC (2000) for requirements and the maximum tolerable concentrations for beef cattle. Tetany (K/Ca + Mg) and milk fever (Ca/P) incidence was calculated on the basis of milliequivalents (meq). Data analysis was conducted based on a completely randomized design with 4 replicates per each plant sample. All data were statistically analyzed using the MSTAT-C computer software package. The means were separated by LSD range test.

3. Results

The macroelement content of forage in quinoa varieties obtained from different sources showed significant differences (Table 1). The phosphorus content of the varieties ranged between 679 and 1802 mg kg^{-1}. The highest P content was found in Red Head variety, followed by the Moqu Arrochilla and Cherry Vanilla varieties. The efficiency of P fertilizer is low in soil, and therefore P deficiency is common in cultivated plants (Sönmez et al., 2016). Phosphorus is one of the most important minerals in the development and maintenance of skeletal tissue in animals, along with calcium. About 80% of phosphorus in the animal body is found in bones and teeth (NRC, 2001). Among the varieties, Rainbow and Oro de Valle cannot meet the P requirements for beef cows, while others meet a minimum level (Figure 1). Forage plants are generally rich in potassium. In potassium-rich soils, plants absorb more potassium than they need, which is called luxury consumption (Kayser and Isselstein, 2005). In this study, all varieties had sufficient potassium content (15,257–23,399 mg kg^{-1}) to meet the needs of beef cows (6000 mg kg^{-1}; NRC, 2000). Quinoa plants have been identified in other studies to have a high K content (Bhargava et al., 2010). Potassium deficiency is rare in animals; it can occur in high-level fattening cattle fed with concentrated feed. On the other hand, an excess of this mineral reduces the absorption and evaluation of Mg (FAO, 2004). In the current study, the potassium ratio of some varieties, such as Cherry Vanilla (23,399 mg kg^{-1}), approached the risky limit (3%; NRC, 2000) for beef cows (Table 1, Figure 1).

The calcium content of the varieties varied between 1047 and 3334 mg kg^{-1} and this range was found to be statistically significant ($P < 0.01$; Table 1). The Ca contents of quinoa varieties are generally high, except for Red Head, and other varieties are at a minimum level (1600 mg kg^{-1}) to meet the needs of beef cows (Figure 1). Debski et al. (2013) also determined that quinoa is rich in Ca and Ca content changes according to the variety. Ca is required for the mineralization and ossification of the growing bone (Köglberger, 2013). Quinoa is rich in Ca, which is an important advantage for animal feeding. Magnesium is necessary for the function of skeletal growth, several enzymes, and muscle function (NRC, 2001). Low

Table 1. Macromineral contents of forage in different quinoa varieties (mg kg^{-1}).

Varieties	P	K	Ca	Mg	S
Titicaca	1304 ^{BC}	17,243 ^{CDE}	1798 ^{BC}	1217 ^{DE}	1080 ^{AB}
Rainbow	679 ^{F}	20,208 $^{A-D}$	3334 ^{A}	1879 ^{B}	979 ^{AB}
Red Head	1802 ^{A}	15,257 ^{E}	1047 ^{C}	962 ^{E}	335 ^{B}
Sandoval Mix	1128 ^{CD}	16,107 ^{CDE}	2897 ^{A}	1537 ^{BCD}	998 ^{AB}
Cherry Vanilla	1531 ^{AB}	23,399 ^{A}	2896 ^{A}	2344 ^{A}	1255 ^{A}
French Vanilla	1104 ^{CE}	21,017 ^{ABC}	3169 ^{A}	1586 ^{BC}	942 ^{AB}
Mint Vanilla	1146 ^{C}	18,167 $^{B-E}$	1765 ^{B}	1460 ^{CD}	477 ^{B}
Oro de Valle	869 ^{DE}	21,863 ^{ABC}	2792 ^{AB}	1794 ^{BC}	1382 ^{A}
Moqu Arrochilla	1682 ^{A}	22,109 ^{AB}	3176 ^{A}	1660 ^{BC}	443 ^{B}
Mean	1249	19,486	2542	1604	877
CV	9.3	10.9	14.2	5.7	12.7
LSD test	276**	4660*	1001**	363**	775*

The means marked with different letters in the same column are statistically different.
*P < 0.05, **P < 0.01

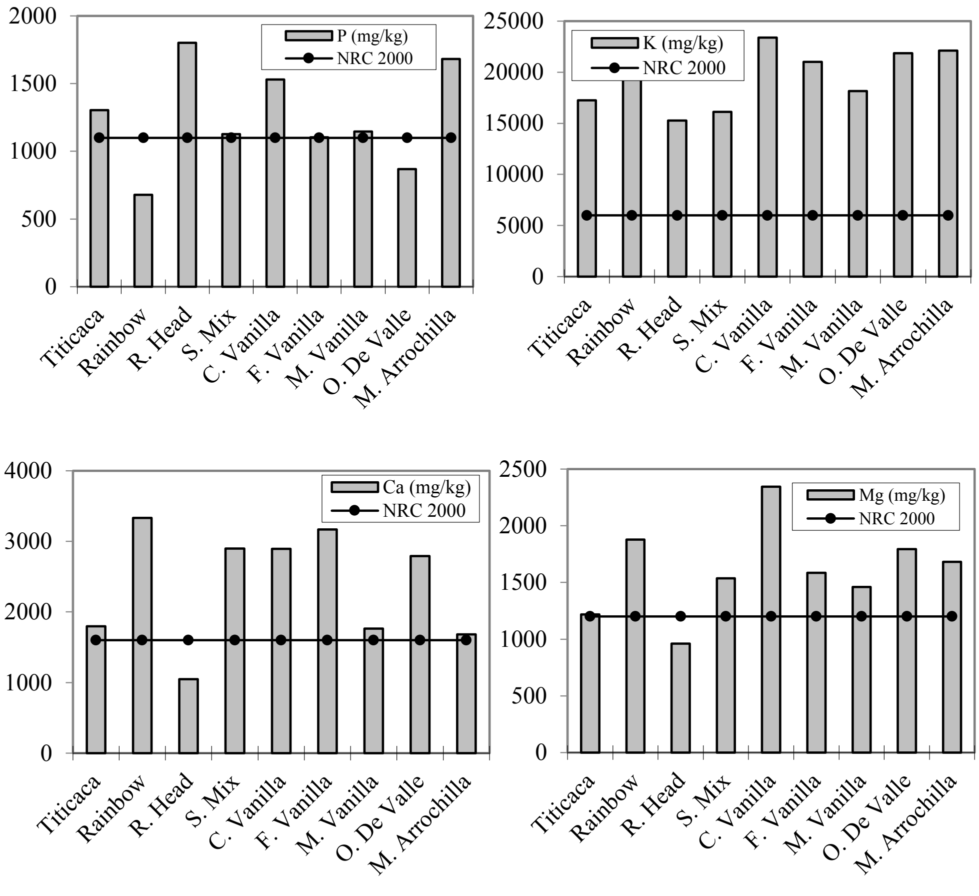

Figure 1. Some macromineral contents of quinoa varieties necessary to meet the requirements of beef cattle according to NRC (2000).

magnesium intake in ruminants results in nutritional disorders called grass tetany (Zelal, 2017). In this study, the Mg content of quinoa varieties showed significant differences, between 962 and 2344 mg kg^{-1}. Nurfeta et al. (2008) have also identified that Mg ratio varies between different varieties of the same plant species. Except for Red Head, other varieties are able to meet the beef cow's Mg requirements (Figure 1).

There were large differences between the sulfur content of quinoa varieties. Oro de Valle and Cherry Vanilla have a high sulfur content, while the Red Head does not. When compared to the NRC (2000) recommendations for beef cows, quinoa forages were inadequate in S concentration (Table 1). Sulfur is found in the structure of amino acids such as methionine, cysteine, homocysteine, and taurine. It is present in a large proportion of body tissues, especially hair, wool, and mohair. For this reason, it is necessary to supply additional S sources in feeds with quinoa.

The present study showed that quinoa varieties are a rich source of iron (265.9–498.6 mg kg^{-1}; Table 2). The results for Fe in the current experiment were similar to those reported by Bhargava et al. (2010). There are significant differences between the varieties in terms of iron content. The reason for this is probably the fact that the varieties have different leaf ratios. Sharma et al. (2012) determined a very high variation in Fe concentration in leaves among the accessions of *Chenopodium* species. The iron content of quinoa varieties in this study is sufficient to meet the requirements of cattle (Figure 2). Iron deficiency is seldom a problem in cattle consuming forages (Arthington, 2002). Copper is necessary for enzyme systems, disease resistance, red blood cell formation, and iron transport and metabolism (NRC, 2001). The copper concentration in forages is usually lower (Espinoza et al., 1991). On the other hand, Cu concentration in quinoa varieties was found to be sufficiently high to meet the requirements of beef cows (10 mg kg^{-1}; NRC, 2000) in this study. It is impossible not to mention the lack of copper for beef cattle in quinoa hay, and in some varieties, such as Rainbow, Cherry Vanilla, and French Vanilla, the Cu content is close to toxic level (Table 2; Figure 2).

There were statistically significant differences between Zn contents (41.3–83.5 mg kg^{-1}) of quinoa varieties. The Cherry Vanilla variety, rich in Fe, Cu, and Mn, had the highest Zn content (85.2 mg kg^{-1}; Table 2). This mineral is required for protein synthesis and metabolism, nucleic acid and carbohydrate metabolism. Relative to the NRC (2000) recommendations for beef cows, the concentration of Zn in the quinoa varieties is adequate (Figure 2). Debski et al. (2018) also observed adequate concentrations of Zn (28.8–72.7 mg kg^{-1}) for beef cattle in the quinoa plants. The concentrations of manganese between the varieties showed great changes and the highest (161.3 mg kg^{-1}) was found in the Cherry Vanilla variety (Table 2). Similarly, Debski et al. (2013) noticed that Mn content varies between quinoa varieties. Manganese is a mineral required for growth and

Table 2. Micromineral contents of forage in different quinoa varieties (mg kg^{-1}).

Varieties	Fe	Cu	Zn	Mn	B	Mo
Titicaca	417.2 ^{ABC}	27.4 ^{C}	52.1 ^{DE}	49.0 ^{D}	11.1	2.5 ^{DE}
Rainbow	466.6 ^{AB}	72.8 ^{B}	79.6 ^{AB}	157.7 ^{A}	9.5	5.7 ^{BC}
Red Head	297.4 ^{BC}	32.5 ^{C}	60.9 ^{BCD}	68.4 ^{D}	8.7	4.8 ^{CD}
Sandoval Mix	287.7 ^{C}	29.3 ^{C}	47.4 ^{DE}	110.8 ^{B}	7.7	2.5 ^{DE}
C. Vanilla	498.6 ^{A}	92.5 ^{A}	85.2 ^{A}	161.3 ^{A}	12.8	1.5 ^{E}
F. Vanilla	265.9 ^{C}	74.2 ^{B}	72.8 ^{ABC}	107.8 ^{BC}	11.7	7.8 ^{AB}
Mint Vanilla	340.0 ^{ABC}	30.8 ^{C}	41.3 ^{E}	78.6 ^{CD}	11.7	8.9 ^{A}
Oro de Valle	311.4 ^{BC}	38.8 ^{C}	55.6 ^{CDE}	124.5 ^{B}	12.1	1.9 ^{E}
M. Arrochilla	329.9 ^{ABC}	40.6 ^{C}	83.5 ^{A}	119.7 ^{B}	12.7	6.0 ^{BC}
Mean	357.2	48.8	64.3	108.6	10.9	4.6
CV	8.3	9.5	8.5	5.3	13.0	11.3
LSD test	173.5**	18.0**	19.5*	30.6**	ns	2.51**

The means marked with different letters in the same column are statistically different.
*P < 0.05, **P < 0.01, ns: nonsignificant

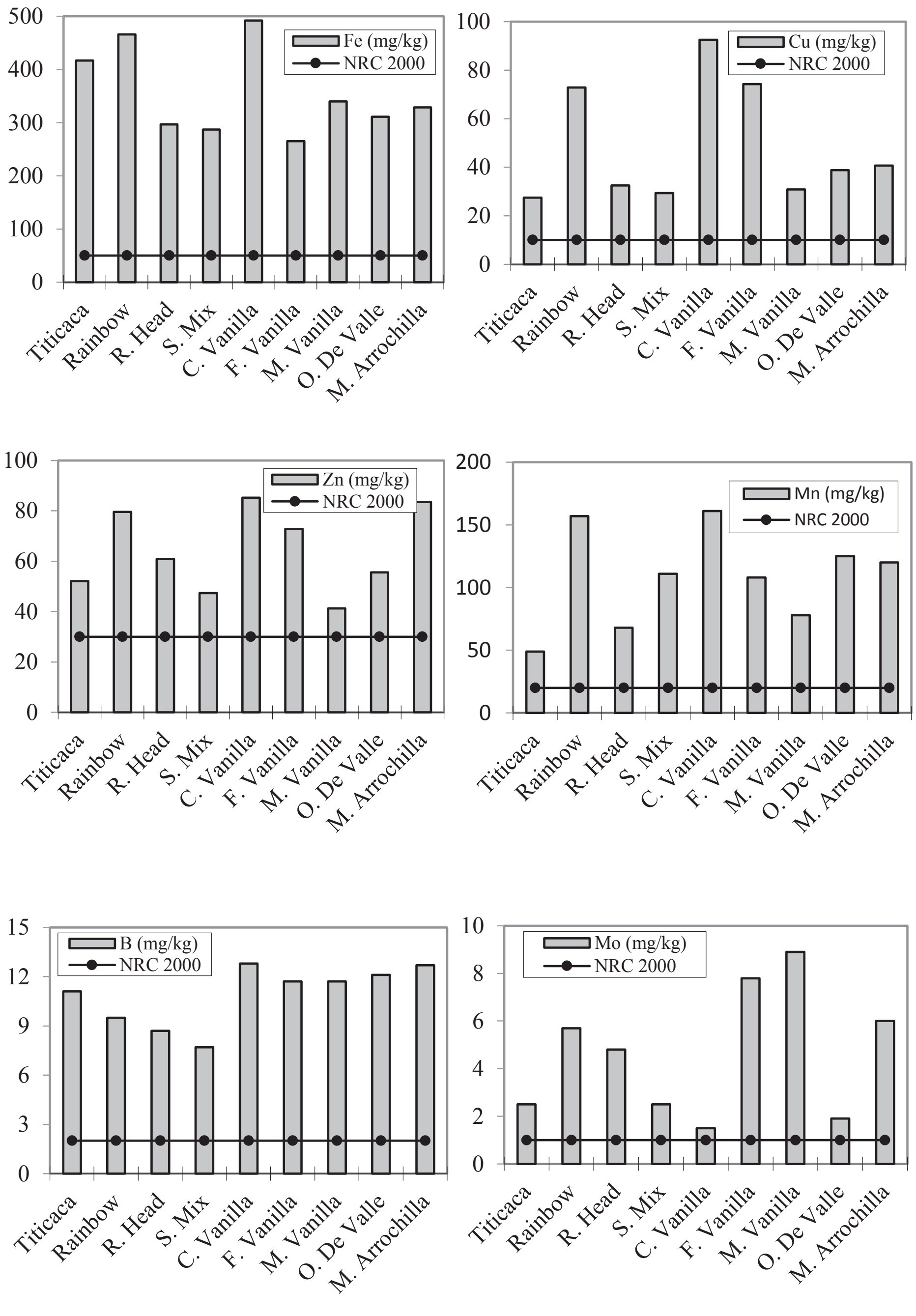

Figure 2. Some micromineral contents of quinoa varieties necessary to meet the requirements of beef cattle according to NRC (2000).

reproductive fertility in animals. In this study, the content of this mineral in the quinoa varieties is sufficient for beef cattle (Figure 2).

The boron contents of quinoa varieties were found to be between 7.7 and 12.8 mg kg^{-1}, and this range was not statistically significant (Table 2). The boron element is required for bone development, brain function, macromineral metabolism, energy substrate utilization, and immune functions in animals (Nielsen, 1997). The boron content of the materials in this study is sufficient for beef cattle (Figure 2). Molybdenum stimulates the activity of the rumen microorganisms in ruminants (Mills and

Bremner, 1980). It meets the needs of the cattle even in low amounts and can cause toxic effects at 5 mg kg^{-1} (NRC, 2000). In this study, the Mo contents of quinoa varieties were between 1.5 and 8.9 mg kg^{-1}. The Mo contents of Rainbow, French Vanilla, Mint Vanilla, and Moqu Arrochilla varieties seem high for cattle (Table 2; Figure 2).

The balance between minerals in animal feed is as important as the amount of minerals in the diet. Interrelationships between the minerals can influence the absorption and utilization of each other. The risk of tetany (hypomagnesaemia) dramatically increases when tetany incidence (K/Ca + Mg) of forage exceeds 2.2 (Aydın and Uzun, 2008). At higher incidence levels, the high potassium ration reduces the availability of calcium and magnesium, which increases the risk of tetany. In this study, the tetany values determined in quinoa varieties ranged between 1.49 and 2.98 (Table 3). The forages of Titicaca, Red Head, and Oro de Valle varieties are considered risky when fed alone.

Calcium has an interrelationship with phosphorus, magnesium, manganese, and zinc (Underwood and Suttle, 1999). The recommended Ca/P ratio is between 1.5 and 2.5 in feeds (Bindari et al., 2013), otherwise a high or low Ca/P ratio is associated with milk fever incidences (Patel et al., 2011). In this study, when evaluated in this respect, quinoa forage in general does not contain a milk fever risk. However, the differences were determined according to varieties. The forages of Rainbow and Red Head varieties appear to be risky with their 3.81 and 0.51 Ca/P values (Table 3). The difference between the varieties is probably due to the difference in the leaf/stem ratios and the corresponding mineral content.

Table 3. Tetany and milk fever incidence of forage in different quinoa varieties.

Varieties	Tetany (K/Ca + Mg)	Milk fever (Ca/P)
Titicaca	2.30 ABC	1.07 DE
Rainbow	1.61 CD	3.81 A
Red Head	2.98 A	0.51 E
Sandoval Mix	1.49 D	1.99 BC
Cherry Vanilla	1.77 BCD	1.48 CD
French Vanilla	1.87 BCD	2.23 BC
Mint Vanilla	2.21 BCD	1.20 DE
Oro de Valle	2.50 AB	2.49 B
Moqu Arrochilla	1.91 BCD	1.48 CD
Mean	2.07	1.80
CV	7.5	13.9
LSD test	0.73*	0.77**
Optimal limits***	< 2.2	1.5–2.5

The means marked with different letters in the same column are statistically different.
*P < 0.05, **P < 0.01, ***Aydın and Uzun (2008); Bindari et al. (2013)

4. Discussion

The mineral content in forages varies according to variety, maturity of the plant, properties of the soil, climate, and the amount of fertilizers used (Swift et al., 2007; Debski et al., 2018). The macro- and micromineral content of hay showed great variations between the quinoa varieties in this study. This difference may be due to some morphological and chemical differences between varieties. Tan and Temel (2017), who examined the same varieties under the conditions of Erzurum, determined that there were differences in plant height, leaf ratio, and dry matter rate. The Cherry Vanilla variety is rich in all minerals except molybdenum. In terms of phosphorus, Cherry Vanilla, Red Head, and Moqu Arrochilla are richer than other varieties. The results of the current experiment indicated that the mineral content of quinoa hay is generally sufficient to meet the requirements of beef cattle, except for sulfur. K and microelement contents of all varieties are sufficient to meet the needs of beef cattle. The molybdenum and boron contents of hay are much higher in some varieties than the animal needs. Although there is usually no risk of tetany and milk fever in the quinoa forage, some mineral imbalances may be observed, depending on the variety. The tetany values of Titicaca, Red Head, and Oro de Valle varieties and the milk fever values of Rainbow and Red Head varieties are outside the optimal limits.

In conclusion, it has been found that quinoa hay can be used in beef cattle feed with some additives and by mixing with other roughages. This plant could play a significant role in providing adequate amounts of both macro- and microminerals in animal feed. Cherry Vanilla, French Vanilla, and Moqu Arrochilla varieties are especially rich in terms of minerals. However, there is a limited number of studies on the use of quinoa in animal nutrition and more detailed studies on its use in animal feeding are needed.

Acknowledgment

This study was supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK Project No: TOVAG-214O232).

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