Journal of Elementology ISSN 1644-2296

Francke A., Młyńska K., Majkowska-Gadomska J. 2021.
Effect of the type of substrate on concentrations of macronutrients and micronutrients in leaves of mizuna grown in containers.
J. Elem., 26(4): 939-951. DOI: 10.5601/jelem.2021.26.3.2174

RECEIVED: 12 August 2021
ACCEPTED: 1 November 2021

ORIGINAL PAPER

EFFECT OF THE TYPE OF SUBSTRATE ON CONCENTRATIONS OF MACRONUTRIENTS AND MICRONUTRIENTS IN LEAVES OF MIZUNA GROWN IN CONTAINERS*

Anna Francke, Kinga Młyńska, Joanna Majkowska-Gadomska

Department of Agroecosystems and Horticulture
University of Warmia and Mazury in Olsztyn, Poland

Abstract

Mizuna (*Brassica rapa* L. var. *japonica)* was grown in a greenhouse experiment conducted in the Experimental Garden at the Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn, in 2017-2018. The experiment had a completely randomized block design. The experimental variables were as follows: (i) two mizuna cultivars: red and green, and (ii) two types of organic substrate: coco coir based substrate and peat. Mizuna plants were grown in 0.5 dm^3 pots placed on movable flood tables; 20 seeds were sown per pot. Edible plant parts were harvested at maturity. The concentrations of the following macronutrients and micronutrients were determined in mizuna leaves: total nitrogen (N_{total}), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), sulfur (S), copper (Cu), iron (Fe), zinc (Zn) and manganese (Mn). The following ratios were also calculated: Ca:P, Ca:Mg, K:Mg, K:(Ca+Mg), K:Ca, N:S, Fe:Mn, Fe:Cu, Zn:Cu, Mn:Zn and Mn:Fe. The yield of fresh mizuna leaves grown in the peat substrate was about 80% higher than that in the coconut substrate. Red cultivar plants had a significantly higher leaf greenness value expressed by the SPAD index. More Ntotal, K and Mg was contained the leaves of mizuna grown in the peat substrate. The edible parts of mizuna grown in coconut substrate were more abundant in P, Ca and S. It was found that the red mizuna leaves in this experiment had a higher content of Ntotal, P, K and S, while the green mizuna leaves had a higher content of Mg and Ca. The proportions of K: (Ca + Mg) and N: S in the mizuna leaves were optimal, Ca: Mg, K: Mg and Ca: P were too wide, and the K: Ca ratio too narrow. The micronutrient concentrations were higher in the red mizuna leaves than in the green mizuna ones. The leaves of the plants grown in the peat substrate had a higher content of Cu, Fe, Zn and Mn compared to the plants grown in the coconut substrate.

Keywords: *Brassica rapa* L. var. *japonica,* substrate, macroelements, microelements.

Anna Francke, PhD, DSc., Department of Agroecosystems and Horticulture, University of Warmia and Mazury in Olsztyn, Pl. Łódzki 3, 10-718 Olsztyn, Poland, phone (89) 523 43 44, e-mail: afrancke@uwm.edu.pl

* The results presented in this paper were obtained as part of comprehensive research conducted at the University of Warmia and Mazury in Olsztyn (grant No. 30.610.016-110). The project was financially supported by the Minister of Education and Science from the program "The Regional Initiative of Excellence" for the years 2019-2022, Project No. 010/RID/2018/19, amount of funding 12,000,000 PLN.

INTRODUCTION

Leafy vegetables are becoming an increasingly important part of the daily diet in Poland. Consumers who are open to new flavours can satisfy their curiosity through a wide range of different vegetables. New vegetable species are being developed, and the once-forgotten ones are being rediscovered. The increased awareness regarding the health benefits of a diverse diet contributes to a gradual change in eating habits. Edible vegetable leaves are a rich source of healthful compounds, and they are characterized by a high nutritional value, desirable flavour and appealing appearance. Leafy vegetable species of the family *Brassicacea* are very healthful because they are abundant in nutrients and bioactive compounds (Artemyeva et al. 2006, Aires et al. 2011, Manchali et al. 2012). Di Gioia et al. (2020) stressed the high biological value of coloured vegetable species containing anthocyanins. One such species is mizuna (*Brassica rapa* L. var. *japonica*). The plant is native to Japan, it has slightly spicy taste and it forms dense rosettes composed of deeply cut, serrated leaves and long narrow stalks (Kalisz et al. 2012, Larkcom 2017, Park et al. 2020). Mizuna is a valuable salad green. Its leaves have a high content of vitamin C, potassium and calcium, and they are used mostly as an ingredient of fresh salads, but they can also be boiled, steamed and pickled (Larkcom 2017, Kopta et al. 2018).

Fresh leafy greens are often sold as cut leaves or components of mixed salads packaged under modified atmosphere, which should be refrigerated and consumed within one or two weeks (Nielsen et al. 2008). Alternatively, leafy greens can be grown and sold in containers to minimize the adverse effects of physiological and microbiological processes, which are often encountered when freshly cut leaves are put on the market. Greens grown in containers also stay fresh for a longer time (Frąszczak et al. 2012).

According to Majkowska-Gadomska et al. (2018), the chemical composition of edible plant parts is largely determined by the type of a growing medium. Inert substrates (rockwool and ceramsite) and organic substrates (peat, tree bark, sawdust, straw and coco coir) play an important role when horticultural crops are grown under cover. A major disadvantage of inert substrates is their difficult disposal, the fact that has prompted producers to search for alternative substrates. Organic substrates are widely available, relatively inexpensive and biodegradable. However, unlike inert substrates, they can considerably reduce nutrient uptake by plants due to their specific properties (Pawlińska, Komosa 2004, Kleiber et al. 2014).

The aim of this study was to determine the concentrations of macronutrients (N, P, K, Mg, Ca and S) and micronutrients (Cu, Zn, Fe and Mn), and their ratios (Ca:P, Ca:Mg, K:Mg, K:(Ca+Mg), K:Ca, N:S Fe:Mn, Fe:Cu, Zn:Cu, Mn:Zn and Mn:Fe) in the leaves of two mizuna cultivars (red and green) grown in a greenhouse in containers filled with two types of organic substrates (coco coir and peat).

MATERIALS AND METHODS

A greenhouse experiment was conducted in the Experimental Garden at the Faculty of Agriculture and Forestry, University of Warmia and Mazury in Olsztyn (20°29′E, 53°45′N; 125 m a.s.l.), in 2017-2018. The experimental factors were as follows: (i) two mizuna cultivars: red and green (Garden Seed and Nursery Stock Company Torseed SA, Toruń, Poland), and (ii) two types of organic substrate: coco coir based substrate and peat. Coco coir (Ceres International Ltd. Pyzdry, Poland) was manufactured using pure coconut fiber, 0-7 mm sieved high-moor peat, sand and perlite. Peat substrate TS3 (Klasmann-Deilmann GmbH, Geeste, Germany) was manufactured using 0-25 mm white moderately decomposed peat with the addition of a wetting agent.

Before the experiment, chemical analyses of both substrates were performed by standard methods. The content of $N-NH_4$ and $N-NO_3$ was determined by the colorimetric method with the use of Nessler's reagent and phenol disulfonic acid, respectively (UV-1201V spectrophotometer, Shimadzu Corporation Kyoto, Japan). The content of P was determined by the colorimetric method (UV – 1201V spectrophotometer, Shimadzu Corporation Kyoto, Japan), Ca and K – by atomic emission spectrometry (AES) (Flame Photometers, BWB Technologies Ltd., Newbury, UK), and Mg – by atomic absorption spectrophotometry (AAS) (AAS1N, Carl Zeiss Jena, Germany). Salinity was determined by the conductometric method (N5773 Conductivity Meter, Tel-Eko Projekt Ltd., Wrocław, Poland), chloride (Cl) content and pH in H_2O were determined by the potentiometric method. The coco coir horticultural substrate was characterized by salt concentration of 0.75 g dm^{-3}, pH 5.53 and the following chemical composition: $N-NO_3$ – 61 mg dm^{-3}, $N-NH_4$ – 67 mg dm^{-3}, P – 92 mg dm^{-3}, K – 215 mg dm^{-3}, Ca – 1225 mg dm^{-3}, Mg – 129 mg dm^{-3}, Cl – 12 mg dm^{-3}. The peat horticultural substrate was characterized by salt concentration of 1.62 g dm^{-3}, pH 6.07 and the following chemical composition: $N-NO_3$ – 129 mg dm^{-3}, $N-NH_4$ – 199 mg dm^{-3}, P – 96 mg dm^{-3}, K – 297 mg dm^{-3}, Ca – 1175 mg dm^{-3}, Mg – 164 mg dm^{-3}, Cl – 14 mg dm^{-3}. Both experimental substrates were enriched with 0.6 kg m^{-3} of a multicomponent fertilizer PG Mix 14-16-18 (Yara) containing 14% N (5.5% $N-NO_3$ and 8.5% $N-NH_4$), 16% P_2O_5, 18% K_2O, 0.8% MgO, 19% SO_3, 0.03% B, 0.12% Cu, 0.09% Fe, 0.16% Mn, 0.20% Mo, and 0.04% Zn.

Mizuna plants were grown in an experimental greenhouse, in 0.5 dm^3 pots placed on movable flood tables. The experiment had a completely randomized block design with three replications (15 pots per replication). Twenty seeds were sown per pot. The recommended cultivation practices for mizuna were applied during the growing season. Greenhouse microclimate conditions were modified to meet the needs of plants in different growth stages, exposed to the natural photoperiod. Mean air temperature in the greenhouse was 22±1°C during the day and 17±1°C at night. Substrate humidity was maintained at 60±5% of the maximum water-holding capacity, initially by sprinkling and later, when the root system had developed, with an automated flood irrigation system. Cultivation tables were flooded with tap water once a day for about 3 min per irrigation. The water level in the tables was raised up to about 3 cm from the bottom of the pots. Crop protection chemicals were not applied. Yellow sticky traps were placed over the pots to control the number of pests (*Trialeurodes vaporariorum* and *Sciara militaris*). *Encarsia formosa* (three individuals per m^2) were used for the biological control of *Trialeurodes vaporariorum*. Before the harvest we measured the leaf greenness index according to the Soil Plant Analysis Development SPAD method (Chlorophyll Meter SPAD 502, Minolta, Osaka, Japan), which is correlated with the chlorophyll content. Plants were harvested 25 days after sowing at consumer maturity. After harvesting, the yield of leaves per pot was determined.

Dry matter (DM) content was estimated by drying a sample of leaves at 105°C in a ventilated oven (FD 53 Binder GmbH, Tuttlingen, Germany) until constant weight.

The concentrations of macronutrients and micronutrients were determined in dry and wet mineralized plant materials in three replications. Plants were dried for 24 h at 65°C in a Binder ED400 dryer (Binder GmbH, Tuttlingen, Germany), and were ground in a Grindomix GM300 knife mill (Retsch GmbH, Haan, Germany). To determine the macronutrient content, herbage samples were wet mineralized in H_2SO_4 with the addition of H_2O_2 as an oxidizing agent using a SpeedDigester K-439 unit (Büchi Labortechnik AG, Flawil, Switzerland). To determine the micronutrient content, herbage samples were wet mineralized in a mixture of HNO_3+$HClO_4$+HCl using a CEM Mars 5 Digestion Oven (CEM Corporation, Matthews, US).

Herbage samples were analyzed to determine the content of total nitrogen (N_{total}) – by the Kjeldahl method, phosphorus (P) – by the colorimetric method (UV-1201V spectrophotometer, Shimadzu Corporation Kyoto, Japan), potassium (K) and calcium (Ca) – by atomic emission spectrometry – AES (Flame Photometers, BWB Technologies Ltd., Newbury, UK), magnesium (Mg) – by atomic absorption spectrometry, AAS (AAS1N, Carl Zeiss Jena, Germany) and sulfur (S) – by the nephelometric method. The concentrations of micronutrients (iron – Fe, copper – Cu, manganese – Mn and zinc – Zn) were determined by AAS (AA-6800, Shimadzu Corporation, Kyoto, Japan). Due to small differences in the obtained values, the results were presented as means from the two-year study. The following weight ratios were also calculated for macronutrients Ca:P, Ca:Mg, K:Mg, K:(Ca+Mg), K:Ca and N:S, and micronutrients Fe:Mn, Fe:Cu, Zn:Cu, Mn:Zn and Mn:Fe.

The results were processed statistically by ANOVA, using Statistica 13.3 software. The significance of differences between means was evaluated by constructing the Tukey's confidence intervals at α=0.05 (TIBCO 2017).

RESULTS AND DISCUSSION

The yield of fresh leaves (FW) of both varieties of mizuna ranged from 9.72 g pot^{-1} (red mizuna, coco coir) to 19.06 g pot^{-1} (green mizuna, peat) – Table 1. The yield of mizuna leaves grown in the peat substrate was 79% higher than that grown in the coconut substrate. Similar results were observed by Zawadzińska et al. (2021), who had the highest fresh aerial mass parts of interspecific geranium (*Pelargonium*) from plants grown in peat substrate. The dry matter (DM) content of the analyzed plant material ranged from 10.35 to 13.27%, in the following order: green mizuna, coco coir > red mizuna, coco coir > red mizuna, peat > green mizuna, peat. Both red and green mizuna tended to accumulate less dry matter when grown in peat (Table 1). Similar results were reported by Kyriacou et al. (2020) for three species of microgreens grown in different potting media. The SPAD leaf greenness index varied widely from 19.6 (green mizuna, peat) to 24.2 (red mizuna, peat) (Table 1). The red cultivar plants had a significantly higher SPAD value. Similar results were obtained by Takahama et al. (2019).

Table 1

Yield, dry matter and SPAD of mizuna leaves (means of data from the two-year study)

Parameter	Yield FW (g pot^{-1})	Dry matter (%)	SPAD
	Cultivar (C)		
Red Mizuna	13.19 ^{a}	10.73 ^{a}	23.8 ^{b}
Green Mizuna	14.62 ^{b}	11.81 ^{b}	20.4 ^{a}
	Substrate (S)		
Coir (CC)	9.95 ^{a}	12.14 ^{a}	22.2 ^{a}
Peat (P)	17.86 ^{b}	10.39 ^{b}	21.9 ^{a}
	C × S		
Red Mizuna × CC	9.72 ^{a}	11.01 ^{a}	23.3 ^{b}
Red Mizuna × P	16.65 ^{b}	10.44 ^{a}	24.2 ^{b}
Green Mizuna × CC	10.18 ^{a}	13.27 ^{b}	21.1 ^{a}
Green Mizuna × P	19.06 ^{c}	10.35 ^{a}	19.6 ^{a}

* Values marked with the same letters do not differ significantly at $p<0.05$.

The total N content of the edible parts of both mizuna cultivars varied widely from 21.60 g kg^{-1} dry matter (DM) (green mizuna, coco coir) to 49.60 g kg^{-1} DM (red mizuna, peat). The leaves of red mizuna contained more total N (by approx. 7%) than the leaves of green mizuna, and mizuna grown in peat had an over two-fold higher total N content than mizuna grown in coco coir (48.30 *vs.* 22.85 g kg^{-1} DM) – Table 2. In a study by Majkowska-Gadomska et al. (2018), total N content was also significantly higher in the rhizomes of ginger (*Zingiber officinale* Rosc.) grown in peat than in coco coir. Barcelos et al. (2016) found that N content was somewhat

Table 2

Content of macronutrients and micronutrients in mizuna leaves
(means of data from the two-year study)

Parameter	Macronutrients					
	N_{total}	P	K	Mg	Ca	S
	(g kg^{-1} DM)					
	cultivar (C)					
Red Mizuna	36.85 ^{b*}	6.60 ^{b}	56.10 ^{a}	3.15 ^{a}	29.25 ^{a}	5.80 ^{b}
Green Mizuna	34.30 ^{a}	5.70 ^{a}	54.45 ^{a}	3.55 ^{b}	31.95 ^{b}	5.35 ^{a}
	substrate (S)					
Coco coir (CC)	22.85 ^{a}	6.40 ^{b}	48.45 ^{a}	3.00 ^{a}	31.05 ^{a}	5.65 ^{b}
Peat (P)	48.30 ^{b}	5.90 ^{a}	62.10 ^{b}	3.70 ^{b}	30.15 ^{a}	5.50 ^{a}
	C × S					
Red Mizuna × CC	24.10 ^{a}	7.00 ^{c}	57.10 ^{b}	3.00 ^{a}	32.10 ^{b}	6.00 ^{c}
Red Mizuna × P	49.60 ^{b}	6.20 ^{b}	55.10 ^{b}	3.30 ^{b}	26.40 ^{a}	5.60 ^{b}
Green Mizuna × CC	21.60 ^{a}	5.80 ^{a}	39.80 ^{a}	3.00 ^{a}	30.00 ^{ab}	5.30 ^{a}
Green Mizuna × P	47.00 ^{b}	5.60 ^{a}	69.10 ^{c}	4.10 ^{c}	33.90 ^{b}	5.40 ^{ab}

Parameter	micronutrients			
	Cu	Fe	Zn	Mn
	(mg kg^{-1} DM)			
	cultivar (C)			
Red Mizuna	4.15 ^{b*}	91.60 ^{b}	56.60 ^{a}	57.60 ^{b}
Green Mizuna	3.95 ^{a}	84.00 ^{a}	54.70 ^{a}	49.70 ^{a}
	substrate (S)			
Coco coir (CC)	3.95 ^{a}	76.50 ^{a}	54.20 ^{a}	46.10 ^{a}
Peat (P)	4.15 ^{b}	99.10 ^{b}	57.10 ^{a}	61.20 ^{b}
	C × S			
Red Mizuna × CC	4.00 ^{a}	80.60 ^{a}	56.20 ^{a}	48.80 ^{a}
Red Mizuna × P	4.30 ^{b}	102.60 ^{b}	57.00 ^{a}	66.40 ^{c}
Green Mizuna × CC	3.90 ^{a}	72.40 ^{a}	52.20 ^{a}	43.40 ^{a}
Green Mizuna × P	4.00 ^{a}	95.60 ^{b}	57.20 ^{a}	56.01 ^{b}

* values marked with the same letters do not differ significantly at $p<0.05$.

higher in the leaves of spinach (*Spinacia oleracea* L.) grown in coco coir, compared with peat, but the noted differences remained within the limits of statistical error.

The P content of the analyzed plant material ranged from 5.60 to 7.00 g kg^{-1} DM, in the following order: red mizuna, coco coir > red mizuna, peat > green mizuna, coco coir > green mizuna, peat. Both red and green mizuna tended to accumulate larger amounts of P when grown in coco coir (Table 2). Similar results were reported by Swetha et al. (2014) for *Aglaonema* grown in different potting media. In a study by Majkowska-Gadomska et al. (2018), substrate had no significant effect on the P content of ginger rhizomes. In the present experiment, P concentrations were higher in the leaves of red mizuna compared with green mizuna (6.60 *vs.* 5.70 g kg^{-1} DM) – Table 2. Similar observations were made by Waterland et al. (2017), who analyzed green and red kale (*Brassica oleracea* L. var. *acephala*).

The K content of mizuna leaves ranged from 39.80 (green mizuna, coco coir) to 69.10 g kg^{-1} DM (green mizuna, peat) – Table 2. Similar K concentrations in mizuna leaves were noted by Acikgoz (2012). In the current study, red mizuna had higher K content than green mizuna (56.10 *vs.* 54.45 g kg^{-1} DM). The concentrations of this macronutrient were also higher in the red-leaved cultivars of kale analyzed by Waterland et al. (2017), Romaine lettuce (*Lactuca sativa* var. *longifolia*) and crisphead 'Iceberg' lettuce (*Lactuca sativa* var. *capitata*) studied by Kim et al. (2016), and butterhead Salanova lettuce (*Lactuca sativa* var. *capitata*) analyzed by El-Nakhel et al. (2019). In the present study, mizuna grown in peat had significantly higher (by over 28% on average) K content than mizuna grown in coco coir (Table 2).

The Mg content of mizuna leaves varied over a relatively wide range of 3.00 to 4.10 g kg^{-1} DM, and it was considerably affected by the genetic factor (varietal traits). Magnesium concentration was highest (4.10 g kg^{-1} DM) in green mizuna, particularly in peat-grown plants (Table 2). Waterland et al. (2017) and Kim et al. (2016) demonstrated that red-leaved kale and Romanian lettuce were more abundant in Mg. In the current study, the Mg content was significantly higher (3.70 g kg^{-1} DM) in the leaves of mizuna grown in peat, regardless of a cultivar. Kyriacou et al. (2020) also observed a positive effect of peat-based substrate on Mg concentrations in coriander (*Coriandrum sativum* L.), kohlrabi (*Brassica oleracea* var. *gongylodes* L.) and pak choi (*Brassica rapa* var. *chinensis*) harvested in an early stage.

In the present experiment, the Ca content of mizuna leaves ranged from 26.40 to 33.90 g kg^{-1} DM, and it was higher (by 9% on average) in green mizuna than in red mizuna (Table 2). A similar trend was observed by El-Nakhel et al. (2019), who examined two cultivars of butterhead Salanova lettuce differing in leaf color. In the current study, the substrate type had no significant effect on the accumulation of this macronutrient in mizuna leaves (regardless of a cultivar), which however tended to be higher in coir-grown plants (Table 2). Jankauskienė et al. (2019) reported that Ca accumulation in young cucumber leaves (*Cucumis sativus* L.) varied depending on a substrate, which is consistent with the findings of Majkowska-Gadomska et al. (2018), who analyzed ginger rhizomes.

Sulphur is a major component of GLS, biologically active compounds with health-promoting properties, which are found in plants of the family *Brassicaceae* (Jankowski et al. 2015). An inadequate S supply, particularly in combination with the optimal N supply, decreases total GLS concentrations in plant tissues (Schonhof et al. 2007). Plants supplied with insufficient S amounts are characterized by lower yields and quality parameters. In the present study, the S content of mizuna leaves ranged from 5.30 to 6.00 g kg^{-1} DM, and these values are double the ones determined by Majkowska-Gadomska and Arcichowska-Pisarska (2014) in the leaves of Welsh onion (*Allium fistulosum* L.) from the family *Alliaceae*. The leaves of red mizuna plants grown in coco coir were more abundant in S (Table 2).

The nutritional value of edible plant parts is affected not only by the concentrations of minerals, but also by their ratios. The optimal ratios between macronutrients in plant-based foods should be as follows: Ca:P – 2:1, Ca:Mg – 3:1, K:(Ca+Mg) – 1.6-2.2:1, K:Mg – 2-6:1 and K:Ca – 2-4:1 (Krzywy et al. 2002, Tariq, Mott 2006, Jarnuszewski., Meller 2013). The above ratios may vary widely depending on numerous factors, such as plant species, plant part, maturity, harvest date and fertilization. Wider than optimal Ca:Mg and Ca:P ratios may be indicative of dietary Mg and P deficiencies. According to Rosanoff et al. (2015), the dietary Ca:Mg ratio should not exceed 2.8:1 since a diet with Ca:Mg > 2.8 may have important health implications, including an increased risk of cardiovascular disease and diabetes. In the current study, the Ca:Mg ratio in mizuna leaves was too wide (8.00:1 to 10.70:1) in all treatments. More desirable values of this ratio were noted in peat-grown plants than in coir-grown plants (8.17:1 *vs.* 10.43:1) – Table 3. Varied and very wide Ca:Mg ratios were also reported by Pitura and Michałojć (2015), who analyzed lettuce (*Lactuca sativa* L. *var. capitata*), kale (*Brassica oleracea* L. var. *acephala*) and celery (*Apium graveolens* L. var. *dulce* Mill.). In the present experiment, the Ca:P ratio in mizuna leaves ranged from 4.26:1 to 6.07:1, and it was too wide in all treatments. The K:Mg ratio in mizuna leaves was also wider than optimal (13.27:1 to 19.04:1), and its value was most favorable (13.27:1) in green mizuna grown in coco coir. Similar observations were made by Majkowska-Gadomska and Arcichowska-Pisarska (2014) in a study on three Welsh onion cultivars. A more nutritionally desirable K:Mg ratio (15.1:1) was noted in green mizuna (Table 3). The K:Ca ratio in mizuna leaves ranged from 1.31:1 to 2.09:1, and its values were close to optimal (2.04-2.09:1) in green and red mizuna grown in peat. The K:Ca ratio was too narrow in coir-grown plants (1.54:1), particularly in green mizuna (1.31:1). The K:(Ca+Mg) ratio in mizuna leaves remained within the normal ranges, and it was too narrow (1.19:1) only in green mizuna grown in coco coir. The K:(Ca+Mg) ratio was more desirable in the edible parts of plants grown in peat, and it was too narrow in coir-grown plants (1.41:1 on average). In contrast, Majkowska-Gadomska et al. (2018) demonstrated that the rhizomes of ginger grown in coco coir were characterized by a more favourable ratio of these macronutrients. According to Krzywy and Krzywy (2001), the N:S ratio in plant tissues should not exceed 15-16:1. In the cited study, the average N:S ratio in the roots of radish (*Raphanus sativus* var. *radicula* Pers.) was 7.05:1. In potato tubers (*Solanum tuberosum* L.), the average N:S ratio was determined at 10.5:1 (Barczak, Nowak 2015). In the current experiment, the N:S ratio in mizuna leaves was in the range of 4.02-8.86:1 (Table 3), which can be considered nutritionally adequate (Schonhof et al. 2007, Krzywy, Krzywy 2001). According to Schonhof et al. (2007), the N:S ratio in plants of the family *Brassicaceae* should vary between 7:1 and 10:1 to promote high yields and enhance overall appearance.

Table 3

Ratios of macronutrients and micronutrients in mizuna leaves (means of data from the two-year study)

Parameter	Macronutrient ratio					
	Ca:Mg	Ca:P	K:Mg	K:Ca	K:(Ca+Mg)	N:S
	cultivar (C)					
Red Mizuna	9.35 [a*]	4.42 [a]	17.88 [b]	1.93 [b]	1.74 [b]	6.44 [a]
Green Mizuna	9.25 [a]	5.67 [b]	15.12 [a]	1.67 [a]	1.50 [a]	6.39 [a]
	substrate (S)					
Coco coir (CC)	8.17 [a]	4.92 [a]	16.15 [a]	1.54 [a]	1.41 [a]	4.05 [a]
Peat (P)	10.43 [b]	5.17 [b]	16.85 [a]	2.06 [b]	1.84 [b]	8.78 [b]
	C × S					
Red Mizuna × CC	10.70 [b]	4.58 [a]	19.04 [b]	1.78 [b]	1.63 [b]	4.02 [a]
Red Mizuna × P	8.00 [a]	4.26 [a]	16.71 [b]	2.09 [c]	1.86 [c]	8.86 [b]
Green Mizuna × CC	10.17 [b]	5.26 [b]	13.27 [a]	1.31 [a]	1.19 [a]	4.07 [a]
Green Mizuna × P	8.33 [a]	6.07 [c]	16.98 [b]	2.04 [c]	1.82 [b]	8.70 [b]

Parameter	micronutrient ratio				
	Fe:Mn	Fe:Cu	Zn:Cu	Mn:Zn	Mn:Fe
	cultivar (C)				
Red Mizuna	1.60 [a*]	22.00 [a]	13.66 [a]	1.02 [b]	0.63 [a]
Green Mizuna	1.69 [a]	21.23 [a]	13.84 [a]	0.91 [a]	0.59 [a]
	substrate (S)				
Coco coir (CC)	1.66 [a]	19.36 [a]	13.72 [a]	0.85 [a]	0.60 [a]
Peat (P)	1.63 [a]	23.88 [b]	13.79 [a]	1.07 [b]	0.62 [a]
	C × S				
Red Mizuna × CC	1.65 [a]	20.15 [a]	14.05 [a]	0.87 [b]	0.61 [a]
Red Mizuna × P	1.55 [a]	23.86 [b]	13.27 [a]	1.16 [d]	0.65 [a]
Green Mizuna × CC	1.67 [a]	18.56 [a]	13.38 [a]	0.83 [a]	0.60 [a]
Green Mizuna × P	1.71 [a]	23.91 [b]	14.31 [a]	0.98 [c]	0.59 [a]

* Values marked with the same letters do not differ significantly at $p<0.05$.

The Cu content of the edible parts of mizuna plants ranged from 3.90 (green mizuna grown in coco coir) to 4.30 mg kg^{-1} DM (red mizuna grown in peat). Red mizuna tended to accumulate more Cu. The leaves of both red and green mizuna grown in peat had higher Cu content than coir-grown plants (4.15 *vs.* 3.95 mg kg^{-1} DM) – Table 2.

The Fe content of mizuna leaves varied between 72.40 mg kg^{-1} DM (green mizuna grown in coco coir) and 102.60 mg kg^{-1} DM (red mizuna grown in peat). Regardless of the substrate type, the leaves of red mizuna had higher Fe concentrations (above 9%). The leaves of both red and green mizuna grown in peat had higher Fe content than determined in leaves of coir-grown plants (Table 2). Different results were reported by Kleiber et al. (2012), who determined that the leaves of tomatoes (*Lycopersicon esculentum* Mill.) grown in coco coir had somewhat higher Fe content than those grown in peat.

Zinc levels in the edible parts of mizuna plants were similar in all treatments, ranging from 52.20 to 57.20 mg kg^{-1} DM. Zinc content was higher in the leaves of red mizuna and peat-grown plants. However, the effects of cultivar, substrate type and their interaction were not statistically significant (Table 4). Waterland et al. (2017) demonstrated that red kale had higher Zn content. Kleiber et al. (2012) found that Zn concentration was twice higher in the leaves of tomatoes grown in peat, compared with plants grown in coco coir.

In the present study, the Mn content of mizuna leaves ranged from 43.40 mg kg^{-1} DM (green mizuna grown in coco coir) to 66.40 (red mizuna grown in peat). The average Zn content was by 16% higher in red mizuna than in green mizuna. Similar relationships were observed by Waterland et al. (2017) in kale, and by Kim et al. (2016) in different cultivars of crisphead 'Iceberg' and Romaine lettuces with variously colored leaves. Average Mn concentration was by 33% higher in the edible parts of mizuna grown in peat than in the leaves of plants grown in coco coir (Table 2).

The nutritional value of vegetables depends on the concentrations of micronutrients in their edible parts, but also by their ratios. The optimal Fe:Mn ratio in plants should equal to 1.5-2.5:1 according to Krzywy and Krzywy (2001). In the current study, the Fe:Mn ratio in mizuna leaves reached 1.55:1 to 1.71:1, and it remained within the normal ranges in all treatments (Table 3). Tariq and Mott (2006) analyzed the uptake of micronutrients by radish leaves and reported the following ratios: Fe:Cu – 14-19:1, Zn:Cu – 4.9-7.2:1, Mn:Zn – 3.2-5.8:1 and Mn:Fe – 1.2-2:1. Based on the above values (Tariq and Mott 2006), the optimal Fe:Cu ratio was noted in the leaves of green mizuna grown in coco coir (18.56:1), being too wide in the remaining treatments. The Zn:Cu ratio in mizuna ranged from 13.27:1 to 14.31:1 – all these values were too wide and did not differ significantly between the treatments. The present findings revealed that according to Tariq and Mott (2006) the Mn:Zn and Mn:Fe ratios in the edible parts of mizuna were too narrow. Similar results were reported by Pitura and Michałojć (2015) in an experiment investigating several leafy vegetable species (lettuce, kale and celery). In the current study, the Mn:Zn and Mn:Fe ratios were close to optimal ones in red mizuna and in leaves of plants grown in peat, compared with coco coir.

CONCLUSIONS

1. The leaves of red mizuna had a higher content of N_{total}, P, K and S, whereas the leaves of green mizuna had a higher content of Mg and Ca.

2. Mizuna grown in peat was more abundant in N_{total}, K and Mg, whereas mizuna grown in coco coir was more abundant in P, Ca and S.

3. From the nutritional perspective, the K:(Ca+Mg) and N:S ratios in mizuna leaves were optimal, the Ca:Mg, K:Mg and Ca:P were too wide, and the K:Ca ratio was too narrow.

4. Micronutrient concentrations were higher in red mizuna leaves than in green mizuna leaves. Plants grown in peat had a higher content of Cu, Fe, Zn and Mn.

5. The Fe:Mn ratio in mizuna leaves was optimal, the Fe:Cu and Zn:Cu ratios were too wide, and the Mn:Zn and Mn:Fe ratios were too narrow.

REFERENCES

Acikgoz F.E. 2012. *Determination of yield and some plant characteristics with vitamin C, protein and mineral material content in Mibuna (Brassica rapa var. nipposinica) and Mizuna (Brassica rapa var. japonica) grown in fall and spring sowing times*. Journal of Tekirdag Agricultural Faculty, 9(1): 64-70. (in Turkish with English summary)

Aires A., Fernandes C., Carvalho R., Bennett R.N., Saavedra M.J., Rosa E.A.S. 2011. *Seasonal effects on bioactive compounds and antioxidant capacity of six economically important Brassica vegetables*. Molecules, 16: 6816-6832. https://doi.org/10.3390/molecules16086816

Artemyeva A.M., Solovyeva A.E., Vavilov N.I. 2006. *Quality evaluation of some cultivar types of leafy Brassica rapa*. Acta Hort., 706: 121-128. DOI: 10.17660/ActaHortic.2006.706.12

Barcelos C., Machado R., Alves-Pereira I., Ferreira R., Bryla D. 2016. *Effects of substrate type on plant growth and nitrogen and nitrate concentration in spinach*. Int J Plant Biol, **7**: 44-47. DOI: 10.4081/pb.2016.6325

Barczak B., Nowak K. 2015. *Effect of sulphur fertilisation on the content of macroelements and their ionic ratios in potato tubers*. J. Elem., 20(1): 37-47. DOI: 10.5601/jelem.2014.19.1.471

Di Gioia F., Tzortzakis N., Rouphael Y., Kyriacou M.C., Sampaio S.L., Ferreira I.C.F.R., Petropoulos S.A. 2020. *Grown to be blue-antioxidant properties and health effects of colored vegetables*. Part II: *Leafy, fruit, and other vegetables*. Antioxidants, 9: 97. DOI: 10.3390/ /antiox9020097

El-Nakhel Ch., Giordano M., Pannico A., Carillo P., Fusco G.M., De Pascale S., Rouphael Y. 2019. *Cultivar-specific performance and qualitative descriptors for butterhead salanova lettuce produced in closed soilless cultivation as a candidate salad crop for human life support in space*. Life, 9: 61. https://doi.org/10.3390/life9030061

Frąszczak B., Kałużewicz A., Krzesiński W., Lisiecka J., Spiżewski T. 2012. *Comparison of four rucola forms grown in containers in different light conditions*. Nauka Przyr. Technol., 6: 1-10.

Jankauskienė J., Brazaitytė A., Kairienė V., Zalatorius V. 2019. *Effects of peat and peat-zeolite substrates on quality, growth indices of cucumber seedlings and crop productivity*. Acta Sci. Pol. Hort. Cult., 18(5): 161-170. https://doi.org/10.24326/asphc.2019.5.16

Jankowski K.J., Budzyński W.S., Kijewski Ł., Zając T. 2015. *Biomass quality of Brassica oilseed crops in response to sulfur fertilization*. Agron. J., 107(4): 1377. DOI: 10.2134/agronj14.0386

Jarnuszewski G., Meller E. 2013. *Mineral element ratios in plants grown on post-bog soils fertilised with zinc and copper*. Folia Pomer. Univ. Technol. Stetin. Agric. Aliment. Pisc. Zootech., 304(26): 25-32. (in Polish with English summary)

Kalisz A., Sękara A., Kostrzewa J. 2012. *Effect of growing date and cultivar on the morphological parameters and yield of Brassica rapa var. japonica*. Acta Sci. Pol.. Hort. Cult., 11(3): 131-143.

Kim M.J., Moon Y., Kopsell D.A., Park S., Tou J.C., Waterland N.L. 2016. *Nutritional value of crisphead 'Iceberg' and romaine lettuces (Lactuca sativa* L.*)*. J. Agr. Sci., 8(11): 1-10. DOI: 10.5539/jas.v8n11p1

Kleiber T., Markiewicz B., Niewiadomska A. 2012. *Organic substrates for intensive horticultural cultures: Yield and nutrient status of plants. Microbiological parameters of substrates*. Pol. J. Environ. Stud., 21(5): 1261-1271.

Kleiber T., Starzyk J., Górski R., Sobieralski K., Siwulski M., Rempulska A., Sobiak A. 2014. *The studies on applying of effective microorganisms (EM) and CRF on nutrient contents in leaves and yielding of tomato*. Acta Sci. Pol. Hort. Cult., 13(1): 79-90.

Kopta T., Jurica M., Pokluda R. 2018. *Oriental brassica vegetables – alternatives for a higher intake of health-promoting substances*. Acta Agrobot, 71(4): 1749. DOI: https://doi.org/ /10.5586/aa.1749

Krzywy J., Baran S., Krzywy E. 2002. *The influence of fertilizers in shaping relations ion K:Mg. K:(Mg+Ca). Ca:P and N:S in cultivated plants*. Zesz. Probl. Post. Nauk Rol., 484: 317-323. (in Polish with English summary)

Krzywy E., Krzywy J. 2001. *N:S and Fe: Mn ionic ratios as indicators of the quality of plant yields received after application of 7 iron (II) sulfate (VI) hydrate*. Fol. Univ. Stetin. Agric., 88: 133-140. (in Polish with English summary)

Kyriacou M.C., El-Nakhel C., Pannico A., Graziani G., Soteriou G.A., Giordano M., Palladino M., Ritieni A., De Pascale S., Rouphael Y. 2020. *Phenolic constitution, phytochemical and macronutrient content in three species of microgreens as modulated by natural fiber and synthetic substrates*. Antioxidants, 9: 252. DOI: 10.3390/antiox9030252

Larkcom J. 2017. *The salad garden*. Frances Lincoln Ltd. Londyn, UK.

Majkowska-Gadomska J., Arcichowska-Pisarska K. 2014. *The effect of Polimag S fertilizer on the macronutrient content of the edible parts of three welsh onion (Allium fistulosum* L.*) cultivars*. J. Elem., 19(3): 709-722. DOI: 10.5601/jelem.2014.19.3.700

Majkowska-Gadomska J., Mikulewicz E., Dobrowolski A. 2018. *Mineral nutrient concentrations in the rhizomes of ginger (Zingiber officinale* Rosc.*) grown in different horticultural substrates*. J. Elem., 23(1): 333-359. DOI: 10.5601/jelem.2017.22.2.1351

Manchali A., Murthy K.N.C., Patil BS. 2012. *Crucial facts about health benefits of popular cruciferous vegetables*. J Funct Foods, 4(1): 94-106.

Nielsen T., Bergstro B., Bor E. 2008. *The origin of off-odours in packaged rucola (Eruca sativa)*. Food Chem, 110: 96-105. DOI: 10.1016/j.foodchem.2008.01.063

Park Ch.H., Bong S. J., Lim [Ch. J.], Kim J.K., Park S.U. 2020. *Transcriptome analysis and metabolic profiling of green and red mizuna (Brassica rapa* L. *var. japonica)*. Foods, 9: 1079. https:// //doi.org/10.3390/foods9081079

Pawlińska A., Komosa A. 2004. *Effect of media and nutrients on the yielding of greenhouse tomato*. Rocz. AR Pozn, 356: 173-180. (in Polish with English summary)

Pitura K., Michałojć Z. 2015. *Influence of nitrogen doses on the chemical composition and proportions of nutrients in selected vegetable species*. J. Elem., 20(3): 667-676. DOI: 10.5601/ /jelem.2015.20.1.760

Rosanoff A., Capron E., Barak P., Mathews B., Nielsen F. 2015. *Edible plant tissue and soil calcium: magnesium ratios: data too sparse to assess implications for human health*. Crop Pasture Sci, 66: 1265-1277. DOI: 10.1071/CP15085

Schonhof I., Blankenburg D., Müller S., Krumbein A. 2007. *Sulfur and nitrogen supply influence growth. product appearance and glucosinolate concentration of broccoli*. J. Plant Nutr. Soil Sci, 170: 1-8. https://doi.org/10.1002/jpln.200620639

Swetha S., Padmalatha T., Dhanumjaya Rao K., Siva Shankar A. 2014. *Effect of potting media on growth and quality in Aglaonema*. J. Hort. Sci., 9(1): 90-93.

Takahama M., Kawagishi K., Sugawara A., Araki K., Munekata S., Nicola S., Araki H. 2019. *Classification and screening of baby-leaf vegetables on the basis of their yield, external appearance and internal quality*. Hortic J, 88(3): 387-400. https://doi.org/10.2503/hortj. UTD-033

Tariq M., Mott C.J.B. 2006. *Effect of boron supply on the uptake micronutrients by radish (Raphanus sativus* L.*)*. J. Agric. Biol. Sci., 1(2): 1-8.

TIBCO *Software Inc. Statistica (Data Analysis Software System, Palo Alto, USA). 2017. Version 13.3*. Available online: https://docs.tibco.com/products/tibco-statistica-13-3-0 (accessed on 25 February 2021).

Waterland N.L., Moon Y., Tou J.C., Kim M.J., Pena-Yewtukhiw E.M., Park S. 2017. *Mineral content differs among microgreen, baby leaf, and adult stages in three cultivars of kale*. Hort Sci., 52(4): 566-571. https://doi.org/10.21273/HORTSCI11499-16

Zawadzińska A., Salachna P., Nowak J.S., Kowalczyk W. 2021. *Response of interspecific geraniums to waste wood fiber substrates and additional fertilization*. Agriculture, 11: 119. https://doi.org/10.3390/agriculture11020119