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Composition of mineral elements and bioactive compounds in tartary buckwheat and wheat sprouts as affected by natural mineral-rich water

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ABSTRACT

The aim was to determine how the nutritional composition of Tartary buckwheat (*Fagopyrum tataricum* Gaertn.) and wheat (*Triticum aestivum* L.) sprouts is affected by the mineral composition of different waters used during their cultivation. We used tap water (TW) and two mineral-rich waters (MRWs), namely moderately mineral-rich water (MMRW) and extremely mineral-rich water (EMRW) originating from springs that contain naturally present mineral elements. Grain germination was not negatively affected by MRWs, however EMRW impeded radicle growth, and consequently prevented sprout development. In comparison to cultivation in TW, cultivation in MMRW resulted in higher Na, Mg, K and Mn concentrations in both sprouts. There were no water-related effects on distribution of mineral elements within plant species, however there were differences in Ca distribution. In Tartary buckwheat Ca was located in inter-vasculature mesophyll, presumably as oxalate crystals. In wheat Ca predominated in epidermis. Only in Tartary buckwheat cultivation in MMRW resulted in less dietary fibre and catechin and more quercetin. By capturing compositional profiles of mineral elements and bioactive compounds in Tartary buckwheat and wheat sprouts we identified the potential for selective enhancement of MMRW. We suggest further work using different spring MRWs to identify optimal conditions for cultivation of different sprouts.

1. Introduction

Mineral element malnutrition has negative influence on human health (Stein, 2010). It is caused by a long-term diet with low concentrations and/or bioavailability of mineral elements. To increase the concentrations and/or bioavailability of mineral elements in diet, agronomic and/or genetic approaches can be used. In addition, appropriate food processing including thermal processing, mechanical processing, soaking, fermentation, and germination can also be applied (e.g., Nelson et al., 2013).

Germinated seeds and sprouts are a particularly rich source of bioavailable mineral elements, along with other bioactive compounds (Nelson et al., 2013). Numerous sprouts with various nutritional qualities are commercially available. Wheat (*Triticum aestivum* L.) sprouts are an excellent source of mineral elements (Plaza et al., 2003; Kulkarni et al., 2006), antioxidants (Alvarez-

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Jubete et al., 2009) and dietary fibre (Koehler et al., 2007). However, germination changes the mineral element content of wheat (Plaza et al., 2003) and significantly increases the soluble dietary fibre content (Koehler et al., 2007). Other nutrient and phytochemical changes that take place after germination of wheat grain have been reviewed recently by Nelson et al. (2013). In contrast to wheat, Tartary buckwheat (*Fagopyrum tataricum* Gaertn.) is one of the less commonly sprouted grains and as such, is less studied. However Tartary buckwheat shows favourable nutritional compositions, with high antioxidative potential and is a rich source of rutin (Kim et al., 2008). There is some evidence that the mineral element composition of both wheat and Tartary buckwheat sprouts can be improved with the use of *artificially produced* mineral-rich water (MRW) for sprout cultivation (Lintschinger et al., 1997; Hsu et al., 2008). In addition, higher antioxidant activity was observed in Tartary buckwheat sprouts cultivated in this artificially produced MRW, without any accompanying changes to the content of rutin, quercetin or crude fibre (Hsu et al., 2008). However, the use of *spring* MRWs, i.e. salty waters that contain *naturally present mineral elements* has not yet been tested in sprout production and cultivation. Therefore, the aim of the study was to test chosen spring MRWs in cultivation of wheat and Tartary buckwheat sprouts and to evaluate how these naturally present mineral elements will influence their mineral element and bioactive compound compositions.

In this study we germinated and cultivated sprouts in tap water (TW) and two spring MRWs (moderately MRW, MMRW and extremely MRW, EMRW) which were chosen based on their mineral element concentrations. We also assessed the mineral element and bioactive compound compositions of the initial grains to quantify the factors of change in the mineral element concentration that take place at the sprouting stage of each plant species. To assess whether water regime can influence the nutritional content of sprouts we measured the following nutritional composition parameters of the sprouts: the concentration and localisation of mineral elements, the amount of total dietary fibre content (i.e., comprising total and individual soluble and insoluble non-starch polysaccharides and lignin with associated polyphenols) and flavonoids (i.e., rutin, quercetin, and catechin).

2. Materials and methods

2.1. Plant material, experimental set-up and sample preparation

We used the Tartary buckwheat cultivar 'Wëllkar', which originates from Luxemburg and was recently reintroduced to Slovenia (Mlin Rangus, Dolenje Vrhpolje at Šentjernej, Slovenia). The grain used in this study came from the second Slovenian cropping (in 2012). For wheat, we used the winter wheat cultivar 'Ficko' as a representative Slovenian wheat cultivar (provided by Agricultural Institute of Slovenia). For both grains, the mature, air dried grain was kept in paper bags in the dark at room temperature. For grain analysis, we homogenised whole grains in liquid nitrogen, using a pestle and mortar (Pongrac et al., 2013). For sprout production, 10 g of grains (~490 of Tartary buckwheat; ~135 of wheat) were placed in an automatic sprouter (EasyGreen® MicroFarm System, EasyGreen Factory Inc., Nevada, USA) where they were watered by misting every 3 h during the day (five times), and twice during the night (with a 4-h and 5-h gap) with the same quantity (i.e., 2.0 L day^{-1}) of either TW or with one of the chosen spring MRWs. Spring water Radenska Classic (Radenska d.d., Radenci, Slovenia) was used as MMRW and Donat Mg® (Droga Kolinska, Adriatic Grupa, Slovenia) as EMRW (Table 1; data provided from the producers), which were selected based on appropriate mineral element composition. These MRWs were not fortified or changed in any way before bottling or before their use in our experiments.

Table 1
Mineral element composition and pH of tap water (TW) and moderately mineral-rich water (MMRW) and extremely mineral-rich water (EMRW) used in experiments, and germination of plant species studied.

	TW[a]	MMRW[b]	EMRW[b]
Mineral elements (mg L^{-1})			
Na	4.4	440	1600
Mg	17.4	95	1060
P	0.01	0.093[c]	<1.0[c]
S	3.71	97[d]	2200[d]
Cl	2.36	44	62
K	1.00	70	15
Ca	72.0	220	340
Mn	0.004	0.27	0.15
Fe	0.11	<0.10	<0.10
Cu	0.01	<1.0	0.007
Zn	2.47	<10	0.022
HCO_3^-	n.m.	2000	7800
pH	7.2	5.6	6
Germination (%)			
Tartary buckwheat	89 ± 3	87 ± 3	83 ± 3.4
Wheat	85 ± 4	83 ± 3	77 ± 4

[a] Measured with inductively coupled plasma-mass spectrometry and inductively coupled plasma-optical emission spectroscopy, except Cl, which was measured with total-reflection X-ray spectrometry.
[b] Data provided by the producers.
[c] Measured as HPO_4.
[d] Measured as SO_4; n.m. not measured.

Three independent experiments were established at room temperature (21 °C) and away from direct sun at a light intensity of 10 μmol m^{-2} s^{-1}. The germination (on 5th day) and pH of the solution (using litmus indication paper; Macherey–Nagel, Macherey–Nagel GmbH & Co., Düren, Germany) were evaluated. We harvested the sprouts eight days after sowing the grains. For buckwheat sprouts this is the optimal time for the simple removal of non-edible husks (Kim et al., 2004). The sprouts (roots and shoots of Tartary buckwheat sprouts, shoots of wheat sprouts) were rinsed with tap water, blotted and weighed (fresh weight). Up to ten individuals were used for cell-type specific localisation analysis, while the rest were freeze-dried for 5 days at 0.240 mbar and −30 °C (Alpha Christ 2–4). The freeze-dried material was weighed (dry weight), homogenised in liquid nitrogen using a pestle and mortar and kept at −20 °C in air-tight containers until chemical analyses. The water content was calculated as the difference between the fresh weight and the dry weight.

For cell-type specific mineral element localisation analysis cotyledons of Tartary buckwheat and wheat sprouts were frozen in liquid propane, sectioned at −25 °C in cryotome to 50 μm thick sections and freeze dried for three days (Klančnik et al., 2014).

2.2. Chemical analyses

2.2.1. Mineral elements

Concentrations of Na, Mg, P, S, K, Ca, Mn, Fe, Ni, Cu, Zn and Mo were analysed in the TW and in the grain and sprout plant material, using inductively coupled plasma-mass spectrometry and inductively coupled plasma-optical emission spectroscopy, as previously described (Pongrac et al., 2013). The Cl concentration in the TW and plant materials was determined by X-ray fluorescence spectrometry, as described by Nečemer et al. (2008). For water analysis, total-reflection X-ray fluorescence spectrometry was used, while the plant materials were analysed by standard energy-dispersive X-ray fluorescence spectrometry, using the Fe-55 radioisotope as the excitation source.

The spatial distribution of Na, Mg, P, S, Cl, K, Ca, Fe and Zn in freeze-dried cotyledon sections was analysed with micro-proton