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Mineral composition of cauliflowers with differently coloured curds modified by the chilling of juvenile plants

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ABSTRACT

An experiment involving five cauliflower cultivars that form curds of different colours (white, green, purple, orange, and romanesco) was carried out to determine the effects of genotype and transplant chilling on the content of 18 major and trace elements. Transplants aged 4.5 weeks were treated with 4 °C or 18 °C temperature for 7 days and then planted in the field. Mature curds were sampled after next 2 months. The use of cauliflower provides new opportunities to study nutrient accumulation in the unique edible organ of the plant formed from meristematic tissues depending on genotype and stress applications. White-curded cauliflower Xenia F_1 usually accumulated the least amount of macro- and micronutrients and the lowest content of N, P, S, B, Fe, and Cu. Romanesco Celio F_1 accumulated the lowest content of Na, Pb, Cr, and Ni but also the highest content of Ca, Mg, S, Cu, Mn, and Zn, indicating this cultivar as valuable component of functional food. Low temperature increased the content of N, P, Ca, S, Mg, Na, B, Cu, Zn, and Pb but decreased the content of Mo and Cr in the curds of certain cultivars. The results demonstrate alterations in plant metabolic pathways due to low temperature applied at the juvenile stage persist through harvest, which proves the existence of stress memory.

1. Introduction

Cauliflower is one of the world's most important vegetable crops and an excellent source of biologically active phytochemicals in the human diet (Podsędek, 2007). Although consumers typically prefer traditional, pure white cultivars, purple-, green-, and orange-coloured curds are also cultivated. Whereas purple cauliflower derives its distinctive deep lavender colour from anthocyanins (Chiu et al., 2010; Scalzo et al., 2008), high concentrations of β-carotene cause cauliflower plant parts to appear orange (Li et al., 2001). The green curd cauliflower is a spontaneous mutation that is unique in changing white tissue green via the ectopic development of chloroplasts in inflorescence meristematic cells (Zhou et al., 2011). Romanesco cauliflowers' fractal-related pyramidal curds are lime green in colour and consist of many pointed pinnacles on their surfaces (Dixon, 2006).

The phytochemicals in vegetable crops, including the *Brassica* genus, are known to be under both genetic and environmental control (Jahangir et al., 2009). Although white cauliflower is rich in vitamins (ascorbic acid; vitamins B_1, B_2, and B_3; folic acid; tocopherols), phenolics, glucosinolates and dietary fibre (Podsędek, 2007), Park et al. (2013) showed significant diversity of health-promoting compounds (carotenoids, anthocyanins, phenolic acids) among white, yellow, green and purple cultivars, implicating the importance of genetic background. Plants belonging to the Brassicaceae family are rich in mineral nutrients compared with other groups of vegetable crops (Cartea et al., 2011). However, mineral content can differ considerably among *Brassica* species and even among crops from the same species (Jahangir et al., 2009; Singh et al., 2013). This is caused mainly by differences in element acquisition from the soil environment by the roots, nutrient movement across the roots and delivery to the xylem, translocation within plants, as well as the ability to accumulate and utilise minerals (Duncan and Baligar, 1990). Thus, a number of differences were reported regarding Ca and Mg concentrations among broccoli inbreds and hybrids (Farnham et al., 2000). Whereas entries with the lowest and highest Ca concentrations differed more than 2-fold, ranges of Mg concentrations in inbreds were similar to those for hybrids. Data published by Singh et al. (2010) revealed variability among 36 cabbage cultivars and germplasms in terms of Fe, Zn, Cu, Mn, K and Ca concentrations. Mineral contents differed among cultivars and germplasms by 6-fold for Fe, 2.4-fold for Zn, 2.1-fold for Cu, 2.3-fold for Mn, 1.7-fold for K and 4-fold for Ca. More recently, Singh et al. (2013) described similar variability in the content of Fe, Zn, Cu, Mn, K and Ca among 71 cabbage

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genotypes. Kopsell et al. (2005) observed that the content of Ca, Mg, K, Fe and Zn among 22 kale and collard cultivars and selections depended on their genetic background, with a 2-fold difference in elemental accumulation measured. However, investigations examining the diversity of mineral composition among various cauliflower cultivars remain scarce, although for some examples see Cebula et al. (2006), Florkiewicz et al. (2014) and Kmiecik et al. (2007). The present study should thus complement this area of research, at the same time emphasizing the importance of selecting cultivars associated with increased essential element uptake to provide human health benefits.

Another aspect of this research was to check the possibility of regulating the mineral nutrient content of various cauliflower genotypes by controlled transplant chilling. Abiotic stresses affect several physiological and metabolic aspects of plant functions (Tuteja and Gill, 2016). Plants subjected to low temperature show changes in chemical composition (Długosz-Grochowska et al., 2012; Hasdai et al., 2006; Nam et al., 2001; Sasaki et al., 1996; Sharma et al., 2012), but most of these studies were performed to assess short-term alterations that occurred in the plants. The effects of transplant chilling on chemical compounds in mature edible plant parts have only been considered in a few studies (Długosz-Grochowska et al., 2012; Kalisz et al., 2015), and less research has been conducted to estimate the influence of low temperature applied to transplants on the subsequent mineral status of mature plants. As an example, Sękara et al. (2015) reported a reduction in the content of mineral elements in the fruits of eggplants chilled at an earlier stage of their ontogeny.

Direct responses in plants grown under low temperature conditions include limited absorption of ions by roots, difficulty in the translocation of elements to the aboveground parts of plants, disrupted distribution of nutrients between plant organs and an overall reduction in nutrient levels in the plants (Lukatkin et al., 2012). However, controlled stress leads to acclimatisation of plants, in which plants alter their subsequent responses to environmental conditions (so-called stress memory) (Bruce et al., 2007). Therefore, alterations in the chemical composition of plants during harvest may differ from short-term effects observed in juvenile plants. Several examples clearly demonstrate a significant role of particular mineral elements in tolerance mechanisms against stress in plants: the K requirement of plants under chilling stress may be related to the inhibitory role of K both against reactive oxygen species (ROS) produced during photosynthesis and in reducing NADPH-oxidizing enzyme reactions (Cakmak, 2005); the production and scavenging of ROS is tightly linked to the presence of some micronutrients such as Zn, Fe, Mn, and Cu in plant tissues because they are metal cofactors of antioxidant enzymes such as superoxide dismutase (Cu, Zn, Mn, and Fe), catalase (Fe), and peroxidase (Fe and Mn) (Hajiboland, 2012); Se strengthens the capacity of plants to counteract oxidative stress associated with the expression of genes involved in antioxidant activities or the Se-induced regulation of general stress resistance mechanisms and the defensive genes of the jasmonic and salicylic acid pathways (Hajiboland, 2012); Ca affects stomatal closure under low temperature conditions, cell structure, and ATPase activity; and Ca ions are secondary messengers that are crucial in the plant response to abiotic stresses through cellular signalling, which also involves Ca-binding sensor proteins such as calmodulins, calcineurin B-like proteins, and Ca-dependent protein kinases (Jaworski et al., 2010; Waraich et al., 2012). Mineral elements play a role in several other physiological and metabolic processes in plants and mitigate the adverse effects of low temperature stress (Cakmak and Engels, 1999). It is not excluded that stress stimuli and further acclimatisation processes will effect permanent changes in metabolic pathways in plants, manifested as alterations of their mineral composition in subsequent stages of ontogeny.

The considerable genotypic variability in cauliflower mineral composition provides an important basis for breeding programmes focused on the development of cultivars possessing increased levels of bioactive compounds and elements, with aim of enhancing the protective capacity of these cultivars as a natural functional food. Controlled stress applied to juvenile plants provides an additional opportunity to regulate the mineral content of edible plant parts. Considering the information described above, we hypothesise that: (1) genetics-based variation among cauliflower cultivars must exist with respect to mineral concentrations; (2) low temperature affects the mineral composition of mature plants due to the existence of stress memory.

2. Materials and methods

2.1. Plant material and experimental design

Five hybrid cauliflower (*Brassica oleracea* L. var. *botrytis*) cultivars with different curd colours and shapes (factor I – cultivar) were involved in a 2-year experiment (2013–2014): F_1 white Xenia (Enza Zaden), F_1 green Vitaverde (Rijk Zwaan), F_1 purple Graffiti (Syngenta Seeds), F_1 orange Sunset (Clause Vegetable Seeds), and F_1 romanesco Celio (Clause Vegetable Seeds). Seeds were sown in March in a greenhouse of the University of Agriculture in Kraków, Poland in 96-cell black trays (the volume of a single cell was 53 cm^3) filled with standard peat substrate (Klasman TS2, Klasmann-Deilmann GmbH, Germany). Temperature in the greenhouse was maintained at 24 °C ± 2 °C until emergence, at which point the temperature was lowered to 18/15 °C ± 2 °C (day/night). In both years, transplant production took approximately 40 days. All transplants were fertilised twice with Kristalon Green liquid fertiliser (Yara International ASA, Poland) (18% N, 18% P_2O_5, 18% K_2O, 3% MgO, and 2% S) at a dose of 10 g/dm^3 water 3 and 4 weeks after sowing and once with 98.5% ammonium molybdate (POCh SA, Poland) ($(NH_4)_6Mo_7O_{24}{\cdot}4H_2O$), which was applied at the end of transplant production at a dose of 1 g/dm^3 water. Four and-a-half weeks after sowing, transplants were transferred to vegetative growth chambers with the temperature (factor II – transplant chilling) set at a constant low temperature of 4 °C or a control temperature of 18 °C for 7 days. Other conditions in both chambers were identical: irradiance (canopy level) was approximately 300 µmol/m^2/s, photoperiod was 14 h (via Sunmaster LM 400-W U46 CDX metal halide lamps, Venture Lighting Europe Ltd., UK), and relative air humidity was approximately 75%.

Transplants were planted in the experimental field of the University of Agriculture in Kraków in southern Poland (50°04′N, 19°51′E) in mid-April and covered with nonwoven polypropylene fleece (Agryl PP, weight of 19 g/m^2). The climate of the region is humid continental (Dfb) according to Köppen's classification. The experimental design used to evaluate cauliflower mineral composition was a split-block withplot; low temperature was the main plot, and cultivar was the subplot, with three replications per treatment. Plant spacing was 50 × 45 cm. A single plot size was 9 m^2 and consisted of 30 plants (24 plants for sampling plus protective rows). The soil type was a Fluvic Cambisol (Humic) according to the classification of the Food and Agriculture Organization of the United Nations. Soil pH (H_2O) was 6.69, soil salinity was 0.50 g NaCl/dm^3 soil, and organic matter was 2.76%. Cultivation practices recommended for cauliflower were used, which encompassed fertilisation, sprinkler irrigation, and plant protection. The amount of fertiliser was calculated on the basis of a soil analysis to achieve the nutrient contents per cubic decimetre of soil of 140 mg of N, 60 mg of P, 200 mg of K, 70 mg of Mg, and 1500 mg of Ca. Several fertilisers were applied to the soil before transplanting. Fifty per cent of the N dose was applied as nitrochalk (Grupa Azoty SA, Poland) (13.5% N-NO_3, 13.5% N-NH_4, 2% CaO, and 4% MgO), and two N doses (25% of the N per each application) were applied as CalciNit (Yara International ASA, Poland) during the plant vegetative phase as calcium nitrate (14.5% NO_3, 1.0% NH_4, and 19.0% Ca). P was applied as single superphosphate (Siarkopol, Poland) (19.0% P_2O_5, 25% CaO, and 32% SO_3), and K was applied as potassium chloride (Luvena SA, Poland) (60% K_2O). Fodder chalk (Jaro SA, Poland), which consists of 93% Ca in the form of calcite ($CaCO_3$), was also used. Borax (Brinkman, Poland)