Nutrient Composition of Perennial Vegetables in Denmark, Sweden, and the United States

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Keywords: perennial, vegetable, nutrition.

Abstract. Twelve species of perennial vegetables were tested for levels of nutrients needed to address common deficiencies. Composition was compared to a set of widely grown and marketed reference vegetables. For seven of the nine nutrients, at least one species had higher content than any reference vegetable, and in the case of Zn, seven species did so. Ten species had more than one nutrient concentration higher than the reference vegetables, with the leaves of *Urtica dioica, Morus alba*, and *Rumex patientia* especially nutrient-rich. Based on their high content of key nutrients, perennial vegetables are worthy additions to gardens and cuisine.

1. Introduction

An estimated 33-56% of cultivated vegetable species are perennial, totaling over 600 species. They occupy only a small fraction of the world's vegetable production area, but offer an option to diversify agriculture. When compared to the world's most widely grown vegetables, many perennial vegetables are much higher in the nutrients needed to address the nutrient deficiencies that impact over 2 billion people (Toensmeier et al 2020).

Perennialization of agriculture offers many benefits to soil health, carbon sequestration, water quality, and other agroecosystem functions (Pimental 2012). Despite this, perennial vegetables as a class have received little attention until recently, even though individual species like globe artichoke (*Cynara scolymus*) and asparagus (*Asparagus officinalis*) are well-researched (Toensmeier et al 2020). Toensmeier et al (2020) synthesized data on the nutritional content of 240 species of perennial vegetables. Many gaps were identified - for some species only partial data, or no data at all, were available.

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This study reports the results of nutritional composition testing of twelve perennial vegetable species from six sites in three countries. These species are *Bunias orientalis, Crambe maritima, Hablitzia tamnoides, Hosta sieboldiana, Hylotelephium telephium, Morus alba, Myrrhis odorata, Rudbeckia laciniata, Rumex patientia, Scorzonera hispanica, Tilia cordata,* and *Urtica dioica.* The focus of this study is on the nutrients that are needed to address deficiencies.

2. Materials and Methods

2.1 Sites

This study reports on research conducted in three countries: Denmark, Sweden, and the United States.

Samples were collected from 5 sites. Several sites use the term "forest garden" to refer to themselves, which is a cold-climate analog of the tropical homegarden, a home-scale multistrata agroforestry system (Toensmeier 2016).

East Hill Tree farm in Plainfield, Vermont, USA, is a nursery for fruit trees and berry plants hardy to northern VT which provides planting, design and pruning - as well as research, propagation, and production of these plants. The farm is located at 472 meters above sea level. The plot where samples were taken from sits on moderately-drained Dummarston silt loam, a former dairy farm and hay field, and was newly worked in 2018 with tillage, mineral amendments, compost and wood chip.

Edgewood Nursery in Falmouth, Maine, USA, is a nursery that produces perennial vegetables, minor fruit crops and ecosystem support plants. The forest garden areas where samples were taken had very weak gravelly soil at the time of first planting 10+ years ago. Current soil conditions vary from patch to patch depending on what materials were used to amend soils over the past decade, but most areas are rich in most nutrients and soil carbon. Combined testing from 2019 shows a PH of 6.3, OM of 6.2%. Zinc was measured at 4.1ppm, which may be relevant to high zinc levels in sampled leaves.

The Farm Between in Jeffersonville, Vermont, USA, is a perennial production farm and nursery, managed with an ecological mindset for the last nearly 30 years. The sea kale bed where broccolis were taken for testing was established as a no-till bed in 2018 and sits in the midst of a perennial polyculture plot including adjacent rows of woody perennial shrubs. Prior to compost, lime and mineral amendments at the time of establishment in 2018, had an organic matter of 6.1%, had a cation exchange of 9.65, and a Ph of 7.2, and were sampled at a depth of 6".

Mångfaldsträdgården (The Diversity Garden) in Stjärnsund, Sweden (60.43461, 16.20565). The Diversity Garden is a public forest garden of about 2700 m^2. The perennial vegetables that were analysed were planted together in the same plot in spring 2018. In a previous study that was conducted in autumn 2018, soil samples (at a depth of 0-30 cm) for nutrient levels, pH and heavy metal levels were measured at the study site. The soil has a clay content of 16% and pH 6.8. The soil is fairly high in nutrient levels, e.g., nitrogen levels (total-N) of 22 mg/kg and phosphorus levels of 260 mg/kg. The carbon content is 16%. The carbon content is much lower, 2.9%, in the soil at a depth of 30-60 cm.

Myrrhis Permakulturhaven is located in Feldballe, Jutland, Denmark, approximately USDA zone 7. The 10,000m^2 site receives 650 mm of precipitation per year, spread throughout the whole year. The climate is classified as humid, semi-continental. The soil type is sandy loam with pH varying between 4,8 and 6.

Puttmyra Forest Garden in Stjärnsund, Sweden, is a 10 year old private forest garden of about 15,000 m^2. The analysed leaves of *M. alba* 'Illinois Everbearing' were grown in an unheated greenhouse in the forest garden. Soil samples were analysed in autumn 2018 at a depth of 0-30 cm. The soil has a clay content of 26% and pH 6.0. The soil has nitrogen levels (total-N) of 19 mg/kg and phosphorus levels of 160 mg/kg.

2.2 Selection of species

This study uses the definition of perennial vegetables from Toensmeier (2020): living for three years or more with more than one year of harvesting; including both woody and herbaceous species, terrestrial and aquatic; with edible leaves or other vegetative parts and/or reproductive structures (flowerbuds, flowers, fruits, and unripe seeds) consumed in salads and main dishes (as opposed to sweet or tart dessert fruits); and excluding root crops and starchy staple fruits like bananas and breadfruit.

Toensmeier (2020) found that data for many species was unavailable, or only available for a few species. Species for this study were chosen for several reasons: to test species currently being marketed; to test species with commercial potential; to test species identified in gardens as having excellent flavor; and/or to fill gaps from Toensmeier (2020).

2.3 Sampling

Species were harvested at the ideal stage for home consumption or marketing as identified by the growers. The time of harvest of the plants was at the peak of ripening. The time of harvest varied between plants and was decided based on when the growers considered it to be optimal. The vegetables were picked, weighed for fresh weight, and photo-documented. The whole leaves were then vacuum packed and kept chilled during the transport to the accredited laboratories. Swedish standard analysis methods for minerals and vitamins in food were used. Two exceptions were the Swedish leaf harvest of *H. tamnoides* and *M. alba,* which were later in the season than ideal, as new time-limited funding appeared for these two extra species. These Swedish *H. tamnoides* were from younger plants than ideal as well.

2.4 Testing

The Swedish and Danish vegetables were harvested, kept away from sunlight in plastic bags and slightly vacuum packed in cooler bags. They were driven to the laboratory within a few hours where they were kept at 5˚C. in the case of Denmark and Sweden but frozen in the US, and shipped to testing facilities. The US vegetables were harvested, vacuum packed, kept away from sunlight and shipped overnight with cooler packs, and kept under refrigeration in the lab until sampled. *B. orientalis, H. tamnoides (#2), H. telephium, M. odorata, R. laciniata,* and *R. patientia,* were tested at Eurofins Steins Laboratorium in Vejen, Denmark. *Crambe maritima (#1&2)* and *H. tamnoides (#1)* were tested at EMSL Analytical in New Jersey, United States. *H. sieboldiana, M. alba, S. hispanica, T. cordata,* and *U. dioica* were tested at ALS Scandinavia, Lulieå, Sweden and ALS Laboratory Group, Prague, Czech Republic. *M. alba* and *H. tamnoides* were tested at Eurofins Food and Feed Testing, Lidköping, Sweden.

The ALS Laboratory Group laboratory uses the following methods. Determination of minerals, analysis with ICP-SFMS was according to ISO (2005) and EPA (1994). Dissolution took place in a microwave oven in closed Teflon containers with HNO3/H2O2/HF. Determination of Vitamin C (ascorbic acid) and ascorbyl-6-palmitate by liquid chromatography according to CEN (2003). Determination of beta-carotene by HPLC with UV detection according to SOP: AM / V / 906. The reporting limit is 0.05 mg/kg and the measurement range is 0.05-3000 mg/kg. Determination of water content at 105 ° C by gravimetric method. Determination of folate, determination of the sum of folic acid + folate according to BVL (2006).

The Eurofins Food and Feed Testing laboratory uses the following methods. Determination of calcium, magnesium, iron and zinc, method reference in accordance with ISO (2016). Vitamin A samples are extracted one time in a mixture of ethanol and hexane and then two times in hexane. The separation is performed by RP HPLC on a C30 column and detected by a diode array detector (DAD) at 450 nm. For quantification a 3-point calibration curve is used. β-carotene is calculated as the sum of all-trans β-carotene, 9Z βcarotene and 13Z β-carotene. 9Z and 13Z β-carotene are calculated using a response factor. Folate samples treated with amylase. Folic acid is extracted, SPE cleaned-up and quantified in LC/MS. For Vitamin C, the sample is extracted in an aqueous solution containing trichloroacetic acid (TCA) and the antioxidant tris(2-carboxyethyl)phosphine (TCEP). Vitamin C is degraded in a basic environment, which the presence of TCA prevents. TCA contributes additionally to trap dissolved proteins. TCEP reduces dehydroascorbic acid (DHAA) to ascorbic acid (AA), so DHAA is also determined and also prevents the degradation of vitamin C. The final extract is analysed by RP-HPLC with UV detection at 265 nm. The Iso-ascorbic acid will be seen as a peak after the ascorbic acid peak. Vitamin E is measured as the content of dl-alpha-tocopherol. Result is expressed in mg dl-alpha-tocopherol /kg.

2.5 Analysis

This study classifies perennial vegetable nutrient concentrations using a scale developed by Toensmeier et al (2020). That study compared perennial vegetables to a group of “reference vegetables” which are globally marketed (see Table X). The reference vegetable species are okra (*Abelmoschus esculentus*), leek (*Allium ampeloprasum*), scallion (*Allium fistulosum*), asparagus (*Asparagus officinalis*), broccoli (*Brassica oleracea* Italica group), cabbage (*B. oleracea* Capitata group), cauliflower (*B. oleracea* Botrytis group), kale and collard greens (*B. oleracea* Acephala group), pak choi and Chinese cabbage (*Brassica rapa*), pepper (*Capsicum annuum*), cucumber (*Cucumis sativus*), summer squash and zucchini (*Cucurbita* spp.), winter squash (*Cucurbita* spp.), globe artichoke (*Cynara scolymus*), lettuce (*Lactuca sativa*), avocado (*Persea americana*), green bean (*Phaseolus vulgaris*), pea (*Pisum sativum*), tomato (*Solanum lycopersicum*), eggplant (*Solanum melongena*), spinach (*Spinacia oleracea*), and sweet corn (*Zea mays*). For each nutrient a scale is used. The reported range for reference vegetables was broken into thirds: “low” for the lowest third, “medium” for the intermediate concentrations, and “high” for the highest. In addition a “very low” category includes results lower than the lowest reported for reference vegetables, “very high” for those higher than the highest reference vegetables, and “extremely high” for those more than twice as high as the highest reference vegetables. See Table X. All nutrient concentrations are presented on a fresh weight basis.

Table 2.1 Nutrient concentration classes based on reference crop nutrient levels
From Toensmeier et al (2020). All are on a fresh weight basis.

	Fiber	**Ca**	**Fe**	**Mg**	**Zn**	**A**	**folate**	**C**	**E**
	%	**mg/100g**	**mg/100g**	**mg/100g**	**mg/100g**	**mgRAE**	**mcg/100g**	**mg/100g**	**mg/100g**
Very low	0.00-0.39	0.00-11.94	0.00-0.46	0.00-11.24	0.00-0.15	0.00	0.00-13.49	0.00-5.64	0.00-004
Low	0.40-1.45	11.85-86.71	0.47-1.01	11.25-35.75	0.16-0.29	0.00-0.18	13.50-73.07	5.65-43.33	0.05-0.73
Medium	1.46-2.50	86.72-161.57	1.02-1.55	35.76-60.26	0.30-0.42	0.19-0.37	73.08-132.63	43.43-79.01	0.73-1.42
High	2.51-3.85	161.58-238.70	1.56-2.11	60.27-85.50	0.43-0.56	0.38-0.55	132.64-194.00	79.02-116.80	1.43-2.54
Very high	3.86-7.15	238.71-477.40	2.12-4.21	85.51-171.00	0.57-1.12	0.56-1.12	194.01-388.00	116.81-233.59	2.55-5.08
Extremely high	7.16+	477.41+	4.22+	171.01+	1.13+	1.13+	388.01+	233.60+	5.09+

3. Results

Table 3.1 presents the nutrient concentration data for the 12 species tested, and notes the part tested and the location of the sampling site. All data are presented on a fresh weight basis. Not all species were tested for all nutrients. Additional nutrients, tested for some species, are shown in the Supplemental Materials.

Table 3.1: Perennial vegetable nutrient concentrations from 5 sites.
All are per 100g fresh weight.

Latin Name	**Edible part tested**	**Sample Location**	**Fiber %**	**Ca mg/100g**	**Fe mg/100g**	**Mg mg/100g**	**Zn mg/100g**	**Vitamin A mg RAE**	**Folate mcg/100g**	**Vitamin C mg/100g**	**Vitamin E g/100g**
Bunias orientalis	leaf	Djursland, Denmark	2.70	170.00	3.70	37.00	0.97	0.20	86.50	83.20	1.26
Crambe maritima #1	inflorescence	Vermont, USA		96.20		31.20		0.35	60.20	24.40	
Crambe maritima #2	inflorescence	Vermont, USA	3.31	125.00	0.81	21.20	0.38	1.22	99.10	55.70	
Hablitzia tamnoides #1	leaf	Stjärnsund, Sweden		66.00	0.59	71.00	0.23	0.25	<5.00	33.90	
Hablitzia tamnoides #2	shoot	Maine, USA	2.74	79.00	1.46	127.00	1.90	0.00	41.20	2.31	
Hosta spp.	shoot	Stjärnsund, Sweden		39.70	0.66	21.90	0.66	0.03	30.20	191.00	
Hylotelephium telephium	leaf	Djursland, Denmark	1.60	84.00	<1.00	14.00	<0.50	0.14	61.90	47.40	1.12
Morus alba	leaf	Stjärnsund, Sweden		780.00	7.70	130.00	1.10	0.27	<5.00	8.13	
Myrrhis odorata	leaf	Djursland, Denmark	4.30	160.00	4.30	50.00	0.90	0.20	130.00	44.30	0.85
Rudbeckia laciniata	leaf	Djursland, Denmark	3.10	160.00	2.30	40.00	1.10	0.30	96.70	33.50	1.02
Rumex patiencia	lead	Djursland, Denmark	3.20	53.00	2.30	33.00	<0.50	0.29	74.30	94.40	1.53
Scorzonera hispanica	leaf	Stjärnsund, Sweden		66.90	0.38	16.3	0.28	0.15	62.40	<0.80	
Tilia cordata	leaf	Stjärnsund, Sweden		83.00	1.28	44.10	0.67	0.15	33.40	<0.80	
Urtica dioica	shoot	Stjärnsund, Sweden		357.00	1.77	56.20	0.73	0.05	157.00	<0.80	

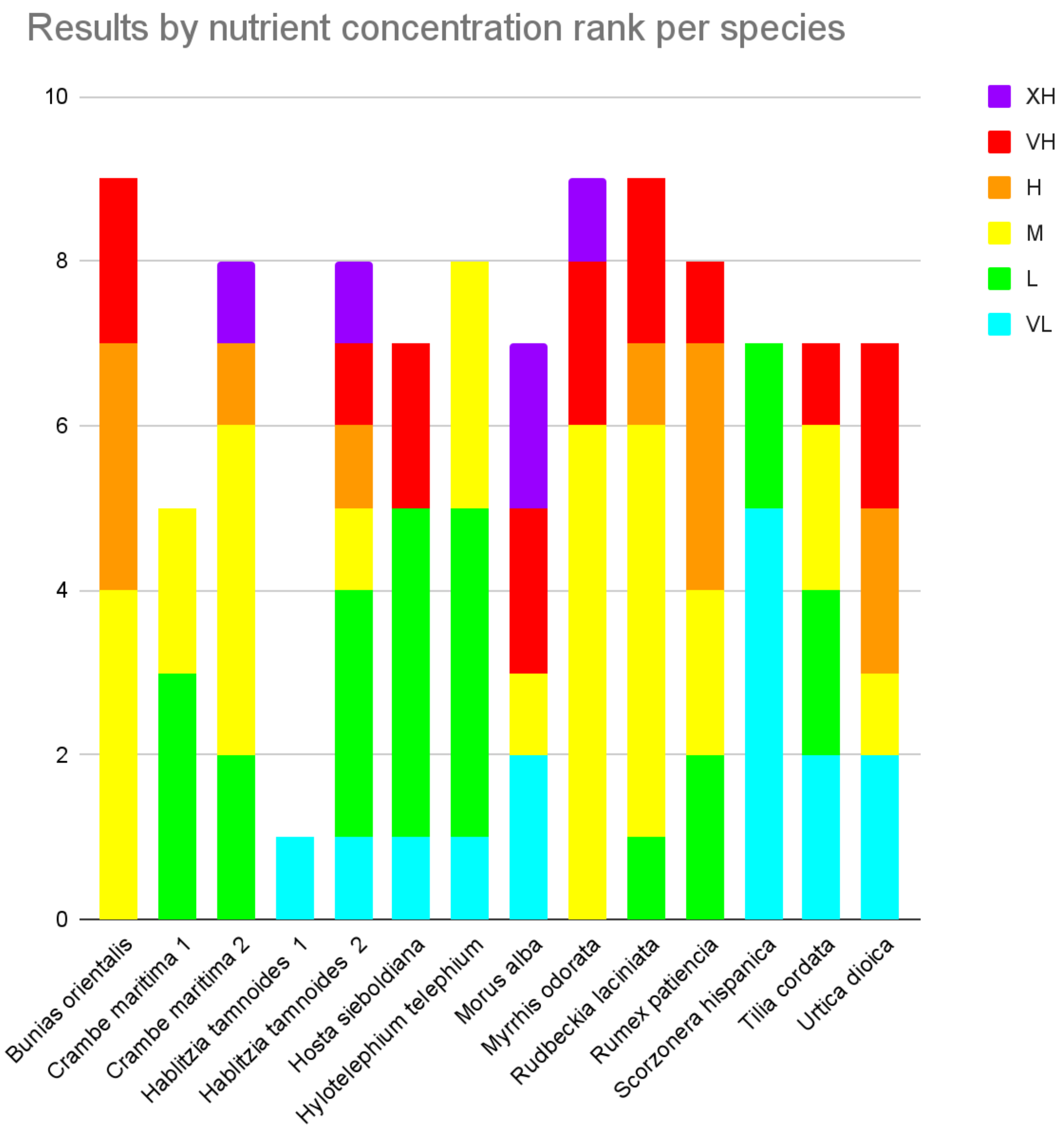
Table 3.2 shows which species ranked high to extremely high in each nutrient. Some results were provided as <X, which in some cases did not permit assigning a concentration level for that nutrient.

Table 3.2 Species ranked high to extremely high in concentration for each nutrient

	Fiber	**Ca**	**Fe**	**Mg**	**Zn**	**Vitamin A**	**Folate**	**Vitamin C**	**Vitamin E**
Extremely high		*Morus alba*	*Morus alba, Myrrhis odorata*		*Hablitzia tamnoides (#2)*	*Crambe maritima (#2), Scorzonera hispanica*			
Very high	*Myrrhis odorata*	*Urtica dioica*	*Bunias orientalis, Rudbeckia laciniata, Rumex patiencia*	*Hablitzia tamnoides (#2), Morus alba*	*Bunias orientalis, Hosta spp, Morus alba, Myrrhis odorata, Rudbeckia laciniata, Tilia cordata*			*Hosta spp.*	
High	*Bunias orientatlis, Crambe maritima (#2), Hablitzia tamnoides, Rudbeckia laciniata, Rumex patiencia*	*Bunias orientalis*	*Urtica dioica*	*Hablitzia tamnoides (#1)*			*Urtica dioica*	*Bunias orientalis, Rumex patientia*	*Rumex patiencia*

Figure 3.1 shows the results by nutrient concentration rank for each species. Species with over 40% of tested nutrients with levels high or higher include *Urtica dioica* (57.14%), *Morus alba* (57.14%), *Rumex patiencia* (50%), and *Hosta* spp (42.86%). Species with 25-39% of tested with nutrients testing high or higher are *Hablitzia tamnoides* #2 (37.50%), *Bunias orientalis* (33.33%), *Myrrhis odorata* (33.33%), *Rudbeckia laciniata* (33.33%), *Tilia cordata* (28.57%), and *Crambe maritima* #2 (25%). Species with less than 25% of levels high or higher are *Scorzonera hispanica* (14.29%), *Crambe maritima* #1 (0%), *Hablitzia tamnoides* #1 (0%), and *Hylotelephium telephium* (0%).

Figure 3.1 Results by nutrient concentration rank per species.



Results by nutrient concentration rank per species

4. Discussion

For all but two of the nine nutrients studied, at least one perennial vegetable had nutrient concentrations higher than the reference vegetables (ranked very or extremely high). In the case of Zn, seven perennial vegetables were ranked very or extremely high. See Table 3.2.

Many perennial vegetables are high in the nutrients needed to address nutrient deficiencies. Ten out of the 12 species tested ranked high or higher in multiple nutrients. See Figure 3.1. The leaves of *Urtica dioica, Morus alba,* and *Rumex patientia* are especially notable in this regard.

No species ranked above “high” for either Vitamin E or folate. In the case of Vitamin E, this may be due to low sample size, as only 5 of the 13 species were tested. Folate results are in line with Toensmeier (2020), which found high levels of folate are rather rare in vegetables whether they are annual or perennial. The reference vegetable *Spinacia oleracea* is among the highest in folate of all vegetable crops. Low folate levels may also be due to a delay before testing at the lab.

5. Conclusions

This study is a contribution to an understanding of perennial vegetable nutrition. The high levels of key nutrients found in some perennial vegetables make them an important resource to address nutrient deficiencies. The high concentrations of these nutrients found in some of these crops provide an additional argument for commercialization.

6. Acknowledgements.

Thanks to crowdsourced experiment.com, where more than 100 backers supported the Swedish research. The testing was performed in the US, with extra funds for testing of *H. sieboldiana* and *H. tamnoides* in Sweden, provided by USDA SARE and USDA Specialty Crop Block Grants. The testing performed by Myrrhis Forest Garden and Agroforestry Project was funded by Fonden for Økologisk Landbrug and Dyrenes Beskyttelse.

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Supplemental Materials

Data on additional nutrients