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Main and Trace Element Contents of Tomatoes Grown in Austria

Manfred Sager
Austrian Agency for Health and Food Safety, Spargelfeldstrasse 191, Vienna A-1220, Austria

Abstract: Tomatoes are one of the most popular and widespread kinds of vegetables on a global scale. Tomatoes of various varieties, sizes and shapes, were grown in 3 different greenhouses in Austria on solid substrates. After freeze drying, they were analyzed for main and trace elements by ICP-OES, ICP-MS, and combustion methods (for C, N). Main inorganic cation was K, whereas contents of hazardous metals (e.g. Cd, Pb), Rare Earth Elements, Si, and Ti were marginal. Due to high water contents, the contribution to the Recommended Daily Intake of essential elements is largely below 1/5 for 1 kg consumption. In spite of different varieties grown at the 3 sites, trends for concentrations versus fruit size could be noted for K, Ca, S, B, Cu, Fe, Zn and Si. Similarly, fruits with seeds + jelly tended to contain more of almost all elements, but less of Li, Ca, Sr, and Ba, whereas P and B were equally distributed. No significant correlations between the concentrations found in tomato-fruits and the amount of soil mobilizable in 0.16 M acetic acid (exchangeable + acid mobile) were found. A look into already published data from other countries reveals that element concentrations met in tomatoes presumably depend on climatic conditions and suitably adapted varieties than on the growing substrate.

Key words: Tomatoes, tomato seeds, trace elements, heavy metals, non-metals, boron, iodine, principal components.

1. Introduction

In Austria in 2015, 97,960 tons of tomatoes were consumed, the internal production of 55,673 tons covered just 57%, though the amount of harvested tons had doubled within the last 15 years (Grüner Bericht BA Agrarwirtschaft). Home production was done in greenhouses at 99.5%. Other sources report a consumption of even 27.2 kg per capita [1], which might include tomato-based products also.

Regarding the budget of trade, tomatoes hold number one among imported vegetables in terms of money (61.5 mill. € net in 2015) and in terms of weight (42.3 mill. tons net in 2015). Beneath from other EU countries, tomatoes were also imported from Albania, Marocco, Tunisia, and Turkey [2, 3].

High consumption rates necessitate controls of products sold at the markets for benefits and risks, as well as investigations about possible contamination sources.

Tomato varieties have been classified due to fruit weight and size. The weight of usual round or egg-shaped tomatoes is 80-100 g, at a size of 47-67 mm. The small-sized cherry-tomatoes are only 16-25 mm of size and 8-25 g of weight. Big-fruit varieties form fruits of up to 250 g [4]. The green colour of non-mature fruits is caused by chlorophyll, which is degraded during maturation, and the antioxidant red colorant lycopin gets formed, which makes 85% of the red dye, in addition to carotin and xanthophyll. The seeds may contain oily substances up to 25% [4]. The effect of removing seeds and surrounding jelly upon elemental composition of tomatoes has not been reported so far.

Tomatoes are grown in all parts of the world and make about 10% of total vegetables. Because growing in the open needs rather warm climate, in moderate climate they are preferably grown protected in greenhouses [4]. The method of cultivation includes the parameters air and soil temperature, light and humidity, planting time, genotype, and available

Corresponding author: Manfred Sager, Dr., research fields: trace and nutrient element analysis and speciation, ecological cycling, food, feeds fertilizers, soils, sediments.

nutrient concentration. Organically grown tomatoes have to be grown in soil, whereas hydroponic or grow-bag-systems are not permitted. Tomatoes need a fertile soil with plenty of organic matter and a pH of around 6.5. In an organic system, high K requirement can be supplied by wood ash added to compost or manures [5]. Because root formation is rather weak, sufficient N-supply has to be provided by high levels of available N in soil [4].

Within recent literature, a wide range of element and trace element contents in tomatoes has been reported, and interelement relations have been investigated by principal component analysis. Due to ample ranges of varieties, substrates, climates and irrigation-fertilization strategies, levels met in tomato fruits are not easily predictable (see discussion).

A compilation of data from tomatoes grown in Austria had not been found so far, particularly organically grown. Because of high consumption rates of the entire population, levels of contaminants and essentials as well as effects of varieties, substrates and growing modes, should be evaluated. A profound dataset of home-grown species might be a precondition to find parameters for the traceability of the origin as well as the culturing method, which is clearly important because major amounts of consumed tomatoes are imported. For authorities, check of labels like “organically grown”, is of major importance.

The seeds might be directly ingested by consumers, but might not be contained in tomato-based products. Thus it was interesting to indicate differences in elemental composition due to seeds and jelly removal.

2. Material and Methods

In summer 2016, 17 samples of different varieties grown at the experimental station of the Federal College for Gardeners at Schönbrunn (Vienna), at Zinsenhof (Lower Austria), as well as in a private garden in Vienna-Donaustadt were grown within greenhouses upon garden moulds. The respective soils were air-dried, sieved and extracted with 0.16 M acetic acid to yield an easily exchangeable and weak acid-leachable soil fraction [6]. The tomatoes were washed, kernels were removed from subsamples, mixed, weighed, freeze dried, and weighed again to determine the water content. The freeze-dried samples were digested in pressure bombs by microwave-assisted heating using two independent methods. Samples of 0.25 g were digested with 3.8 mL 16 M HNO_3 + 0.1 mL 26 M HF, and made up to 25 mL. In parallel 1.00 g samples were digested with 8 mL 7% $KClO_3$ solution in diluted (4.5 M) HNO_3 (20 g $KClO_3$ p.a. + 200 mL H_2O + 80 mL HNO_3 suprapure), and also made up to 25 mL [7]. The $KClO_3$ digests are especially suitable for boron, sulfur and iodine analysis, and develop much less internal pressure. As device, an MLS 1200 mega high performance microwave digestion unit (MLS GmbH, D-88299 Leutkirch) was used, programmed at 3 min 250 W/2 min 0/5 min 250 W/5 min 400 W/5 min 500 W. Because as boron and silicon were also determined also, contact with glass had to be strictly avoided.

For ICP- multi-element determinations, a Perkin-Elmer Optima 3000 XL instrument with axial torch was used for ICP- multi-element determinations. For determinations in the $KClO_3$- digests, matrix-matched calibrants were used for determinations after $KClO_3$- digests. The non metals and La-Ce-Y-Sc-Ti were obtained from separate runs. ICP-MS measurements for Bi, Cd, Co, Mo, Ni, Pb, Tl, as well as Y and the Rare Earth Elements were performed with an Perkin Elmer Sciex ELAN DRC II at 1+9 dilution, after the addition of indium as internal standard. Total iodine was measured in a separate run as the iodate after 1+9 dilution with 1/80 diluted 7% $KClO_3$ digestion solution (as above) and evaluated by standard addition.

The solid samples were directly used to determine C and N by combustion method.

Concentrations in the original tomatoes were recalculated using the water loss determined by freeze drying.

3. Results and Discussion

3.1 General

Like in other investigations, water contents of fresh tomatoes were rather high at 93.3 ± 1.1 %.

High K content of tomatoes has been confirmed. K/Rb proportion was very high, indicating strong selection of K versus Rb, or adequate K supply (Tables 1 to 5). Total nitrogen averaged rather high at 2.56%.

Almost all samples were homogenized with seeds (including the jelly) and without. For ketchup and other tomato-containing products, seeds and jelly get usually removed, whereas for home consumption and salads, the fruits are usually consumed as such. Comparison of the datasets with and without these seeds (with respect to dry mass) revealed enrichment of several elements within the seeds, except for Li, Sr, Ca, and Ba. Boron and phosphorus were equally distributed (Table 2).

From factor weights of principal component analysis (Table 3), related element combinations get indicated, which rely on simultaneous or antagonistic uptakes. In this case, nutrients N and K went along with Mg, Na, Rb, Cs, and Co. Mg and Ca-Sr-Ba were met in different principal components and seem to act independent from one another. Ca-Sr-Ba contents were related to Cu, Zn, Cd, Al, as well as S and Si. The anions B and P together formed a component of its own. The relationship Mn-Mo was found by other authors also.

Component 1 (N-K-Na-Rb-Cs-Co) and Component 2 (Al-Ca-Sr-Ba-Cd-Cu-S-Si) obtained from principal component analysis, met within different fields when assigned to the 3 sampling locations. Principal components listed in respective references, however, showed other interelement relations then were found within this work.

Classification of the sampled varieties according to fruit size in cherry tomatoes, round tomatoes and big tomatoes, revealed decreasing trends of C, Li, and J, but increase of K, Ca, Ba, Cu, Fe, Zn, B, Si and S with increasing size with respect to dry weight (Table 4).

3.2 Effects of Site and Varieties

Titanium, Beryllium, Vanadium, Scandium, Yttrium and the Rare Earths were largely below the detection limits, and thus cannot be used as indicators of the geochemical background of the site.

Unfortunately, tomatoes of different varieties were grown at all 3 sites (Table 6), which makes it more difficult to driscriminate between effects of available soil fractions and varieties upon the actual element contents. But unless no differences between the 3 sites were noted, effects of soil and variety seemed marginal, or there was sufficient supply at least, resp. the soils were similar. This was the case for %N, Mg, Mn, P, J, B, and Pb. Different concentration ranges, however, should be traceable to transfer from soils, if an easily mobilizable fraction had the same trend. Because alkali and alkaline earth concentrations were particularly different between the 3 sites, a mobile soil fraction was chosen which presumably matches well with plant uptake, which was dilute acetic acid (0.16 M). Similar trends between Li and Na in tomatoes and acetic acid soluble soil fractions, as well as possibly also for K, Zn and Fe, were observed. In case of Sr, Ba, S, as well as the trace elements Al, Cd, Co and Ni, this was not the case, indicating a rather strong effect of the sampled varieties (Table 5).

3.3 Relations to Growing and Fertilization Conditions from References

When 7-week old tomato seedlings (variety Super Momatarou) were hydroponically grown in Hoagland solution without additional boron supply, fruit clusters reached just 5.5 mg/kg, but at 0.5 mg/L B, they got 27.8 mg/kg d.m. Boron-deficiency led to a 87% decrease of K in the fruits, decrease in photosynthetic rate, and a decrease of dry weight of all plant organs. Ca decreased in the leaves, but increased in all other tissues, and Mg also increased in all tissues [8].

Within the current work, however, Boron contents in the fruits of 8.56 ± 1.97 mg/kg dry mass were obtained, and no significant differences of fruit or soil boron levels between the 3 locations were noted. This means that the differences between the varieties were larger than between the locations.

Additional foliar application of a cocktail of nutrient and trace elements to hydroponically greenhouse-grown tomato plants caused significant increases of applied element concentrations in the fruits also. But even without additional spraying, levels of Na, Fe, Mn, Zn and Cu have been reported higher than in this work [9].

Imhof et al. [10] compared trace element levels in tomato fruits grown in artificial sustrate hors-sol, in Swiss soil from Wallis, and in Spanish soil. Soil-grown tomatoes contained more Co, Ni, Sr and Li, but equal amounts of Na, Mg, and Ca, comparing to grown on hors-sol. Differences due to soil location were found for Li, Na, Ca, Al, Mn, Zn, Co, and Mo. Soil-grown big-fruit varieties took more Cu and Ni than fruits of usual size. Maximum contributions for discrimination of both fruit size and growing technique were obtained for Li, Zn and Ca [10].

3.4 Relations to Data from Other Regions

Because tomatoes are grown worldwide, it is interesting to compare the data obtained within this work with reports from elsewhere. Beneath varieties and substrates used, climatic and growth conditions seem to be of great influence which will be pointed out in the subsequent review. Concentration levels encountered within this work (Table 1) were similar to those reported from hydroponic cultures in Germany and Denmark [11], whereas concentration levels found in tomatoes from the Mediterranean (Spain [12], Turkey [13]) or South America [14] were much higher, particulary for Cd, Al and Fe. From Thailand, however, even lower levels have been reported [15].

Bressy et al. [14] compared element contents of tomatoes of variety “Italy”, organically and conventionally grown, and randomly collected from municipal markets in Salvador, Bahia, Brazil. In conventionally cultivated tomato samples (varieties Khaki, Cherry, and “Italy”), most element concentrations in dry weight steadily increased from early to final maturation, except Ba, Mn, Cd, Hg, and Se. With respect to levels met in this work, organically grown tomatoes (var. Italy) from Salvador, Bahia, Brazil, contained higher levels of Al, Fe, Co, Cr, and V, but lower levels of Ba, Sr, Ni, and Zn, whereas Cu, Mn and Cd were about equal. This might be due to tropic conditions [14].

Tomato varieties from Spain, Ecuador and Peru, cultivated in a greenhouse in Valencia, contained significantly more Na, Ca, Cu, Fe, Mn and Zn than samples treated within this work, whereas they were equal in Mg and even lower in K. Spanish tomato cultivars contained lower levels of Na, K, Ca, Fe, and Mn than wild forms from the original habitats in Peru and Ecuador, but more Zn. Similarly, hierarchic clustering of total element data revealed significant groupings of cultivated and wild varieties. Principal component analysis of all cultivated and wild forms from South America and Spain revealed relations between Na-K-Ca-Mg [16], whereas among current data, relations Ca-Zn, Na-K, and Mn-Mo were found in separate components.

Tomatoes ecologically grown with additions of compost-based fertilizers, were collected at 13 orchards in the Basque Country in 2010, and contained higher levels of all trace element cations investigated, particularly Cr, Al, V, Co and Pb. Some significant binary correlations between Cr-V (0.99), Cr-Fe (0.86), V-Fe (0.86), Fe-Mn (0.69) and Fe-Al (0.58) were found. This could be due to geogenic effects, but also to soil contaminations [12]. There was no evidence, however, between quasi-total metal contents in the top soils (0-25 cm) and the contents in the fruits, except for Mn, in spite of same variety and year, though some sites were heavily contaminated with Cd, Pb and Zn [12].

Table 1 Results for element contents of tomatoes, mg/kg, assorted for descending element contents. Element symbols given in italics refer to ICP-MS data, C and N to combustion, and the rest to ICP-OES.
DACH-RDI = recommended daily intake from a council of Germany, Austria and Switzerland.

In dry weight			In wet weight	DACH-RDI	
Mean ± std.dev	Median		Mean ± std.dev	Median	mg per day
428,400 ± 11,000	426,700	C			
31,980 ± 16,140	27,885	K	1,939 ± 569	1,785	
23,900 ± 3,500	23,700	N			
2,850 ± 664	2,910	P	190 ± 54	181	700
1,584 ± 501	1,456	Ca	104.2 ± 28.6	92.3	1,000
1,584 ± 202	1,589	S	88.2 ± 35.8	95.1	
1,253 ± 270	1,242	Mg	83.4 ± 19.6	80.1	350-400
327 ± 147	306	Na	21.9 ± 11.5	20.7	550
21.9 ± 15.1	17.1	Si	1.38 ± 0.80	1.23	
19.3 ± 8.0	17.4	Fe	1.303 ± 0.595	1.093	10-15
17.6 ± 8.0	17.3	Zn	1.177 ± 0.571	1.035	7-10
8.56 ± 1.97	8.51	B	0.565 ± 0.102	0.545	
7.99 ± 2.40	8.05	Mn	0.534 ± 0.189	0.482	2-5
5.95 ± 3.48	4.64	Rb	0.397 ± 0.253	0.321	
4.15 ± 1.61	3.99	Cu	0.273 ± 0.095	0.273	1-1.5
1.90 ± 1.06	1.81	Sr	0.124 ± 0.066	0.123	
1.39 ± 0.81	1.09	Al	0.106 ± 0.078	0.076	
0.48 ± 0.23	0.45	Ba	0.0306 ± 0.0127	0.0285	
0.466 ± 0.096	0.45	Mo	0.0313 ± 0.0093	0.0303	0.075-0.25
0.290 ± 0.134	0.247	Ni	0.0197 ± 0.0101	0.0178	
0.127 ± 0.097	0.076	Li	0.0096 ± 0.0082	0.0077	
0.034 ± 0.046	0.042	Cr	0.0023 ± 0.0030	0.0030	0.05-0.5
0.045 ± 0.021	0.037	Cd	0.0029 ± 0.0012	0.0029	
0.018 ± 0.007	0.018	Co	0.0012 ± 0.0005	0.0012	
< 0.001-0.042	0.015	Pb	< 0.0002-0.0039	0.0010	
< 0.001-0.066	0.011	I	0.0019 ± 0.0032	0.0009	0.15
0.0039 ± 0.0032	0.0031	Cs	0.0003 ± 0.0002	0.0002	
< 0.1	< 0.1	Sc	< 0.01	< 0.01	
< 0.07-0.19	< 0.07	Ti	< 0.003-0.013	< 0.003	
< 0.05	< 0.05	V	< 0.001	< 0.001	
< 0.008	< 0.008	Ce	< 0.0005	< 0.0005	
< 0.005	< 0.005	Nd	< 0.0003	< 0.0003	
< 0.004-0.009	< 0.004	La	< 0.0002-0.0004	0.0002	
< 0.003	< 0.003	Tl	< 0.0002	0.0000	
< 0.002	< 0.002	Be	< 0.0001	< 0.0001	
< 0.002	< 0.002	Sm	< 0.0001	< 0.0001	
< 0.001-0.003	< 0.001	Y	< 0.00007-0.00016	< 0.00007	
< 0.001	< 0.001	Pr	< 0.00006	< 0.00006	
< 0.0005	< 0.0005	Gd	< 0.00003	< 0.00003	
< 0.0003	< 0.0003	Er	< 0.00002	< 0.00002	
< 0.0002	< 0.0002	Tb	< 0.00001	< 0.00001	
< 0.0002	< 0.0002	Eu	< 0.00001	< 0.00001	
< 0.0002	< 0.0002	Lu	< 0.00001	< 0.00001	
< 0.0001	< 0.0001	Ho	< 0.00001	< 0.00001	

Table 2 Proportion of concentrations with seeds/concentrations without seeds, assorted according to enrichments in the seeds (+ jelly), from dry mass data.

	Mean ± std.dev
Li	0.80 ± 0.51
Sr	0.84 ± 0.28
Ca	0.91 ± 0.19
Ba	0.92 ± 0.19
B	1.00 ± 0.20
P	1.01 ± 0.43
C	1.02 ± 0.02
Rb	1.03 ± 0.19
K	1.03 ± 0.22
Si	1.03 ± 0.21
S	1.05 ± 0.06
Zn	1.09 ± 0.11
Mo	1.10 ± 0.22
Co	1.11 ± 0.26
Mg	1.12 ± 0.23
N	1.13 ± 0.18
Cd	1.22 ± 0.36
Na	1.23 ± 0.56
Cs	1.24 ± 0.66
Ni	1.29 ± 0.63
Cu	1.29 ± 0.37
Mn	1.42 ± 0.51
Fe	1.57 ± 0.94
Al	1.67 ± 1.18

Table 3 Factor weights obtained in principal component analysis, all data.

Component matrix[a]				
	Component			
	32.0%	24.9%	13.0%	7.3%
N	0.298	0.697	0.139	-0.349
Al	0.636	0.012	0.175	-0.248
B	0.280	0.354	0.336	0.690
Ba	0.840	-0.196	-0.137	0.286
Ca	0.775	-0.465	0.136	0.176
Cd	0.818	-0.201	0.090	-0.011
Co	0.262	0.690	0.253	0.124
Cs	0.232	0.851	-0.282	0.081
Cu	0.912	-0.024	0.019	-0.184
Fe	0.331	0.452	-0.412	-0.306
K	0.246	0.766	-0.435	0.061
Li	0.730	0.362	0.343	0.010
Mg	0.414	0.632	0.522	0.074
Mn	0.045	0.492	0.720	-0.134
Mo	0.251	0.269	0.743	0.093
Na	0.017	0.724	-0.105	0.326
P	0.289	0.144	0.284	-0.712
Rb	0.187	0.770	-0.515	0.079
S	0.807	0.249	0.329	-0.021
Si	0.947	-0.148	-0.056	0.101
Sr	0.696	-0.590	0.105	0.144
Zn	0.669	0.411	-0.447	-0.071

Table 4 Discrimination of selected elements according to size, all sites (dry weight, seeds included), mean and standard deviation.

	Cherry tomatoes	Round and egg-shaped	Big size
% C	44.06 ± 0.41	43.73 ± 0.84	42.27 ± 0.84
% N	2.58 ± 0.28	2.53 ± 0.18	2.57 ± 0.38
B	7.06 ± 1.03	7.49 ± 2.27	10.55 ± 1.41
Ba	0.29 ± 0.17	0.36 ± 0.11	0.71 ± 0.25
Ca	1 159 ± 174	1 509 ± 325	1 608 ± 633
Cd	0.042 ± 0.004	0.041 ± 0.023	0.054 ± 0.026
Co	0.018 ± 0.007	0.014 ± 0.004	0.026 ± 0.003
Cr	0.052 ± 0.012	0.075 ± 0.022	0.039 ± 0.072
Cs	0.0041 ± 0.0023	0.0028 ± 0.0022	0.0066 ± 0.0047
Cu	3.83 ± 0.99	4.04 ± 1.69	5.32 ± 1.44
Fe	18.5 ± 3.6	22.7 ± 9.3	24.0 ± 8.2
I	0.050 ± 0.058	0.033 ± 0.027	0.032 ± 0.042
K	23,425 ± 2,391	26,182 ± 5,805	49,391 ± 25,906
Li	0.202 ± 0.111	0.113 ± 0.109	0.080 ± 0.079
Mg	1 334 ± 225	1 176 ± 215	1 448 ± 331
Mn	10.18 ± 2.31	8.52 ± 2.50	8.63 ± 1.93
Mo	0.565 ± 0.111	0.453 ± 0.100	0.455 ± 0.086
Na	388 ± 241	261 ± 112	447 ± 114
Ni	0.27 ± 0.11	0.35 ± 0.15	0.35 ± 0.17
P	2,966 ± 239	3,238 ± 601	2,701 ± 1,249
Pb	0.013 ± 0.008	0.014 ± 0.013	0.017 ± 0.018
Rb	4.62 ± 0.92	4.15 ± 0.89	10.29 ± 4.98
S	1,389 ± 20	1,610 ± 165	1,779 ± 145
Si	12.8 ± 5.9	18.8 ± 11.2	35.6 ± 18.8
Sr	1.50 ± 0.45	1.47 ± 0.92	1.71 ± 1.49
Zn	14.4 ± 5.1	15.2 ± 6.9	25.4 ± 7.4

Table 5 Possible relations between concentrations found in tomatoes (with seeds, in dry mass) and the acetic-acid mobile soil fraction (0.16 M).

	Zinsenhof		Schönbrunn		Donaustadt	
mg/kg	Tomato	Soil	Tomato	Soil	Tomato	Soil
Al	2.56	3.0	1.58	1.6	0.62	20.1
B	8.36	2.48	8.37	2.24	11.47	2.5
Ba	0.65	13.8	0.27	12.1	0.59	6.79
Ca	1,907		1,291		1,237	8,394
Cd	0.067	0.048	0.036	0.060	0.035	0.040
Co	0.018	0.22	0.019	0.15	0.026	0.06
Cr	0.038	0.028	0.073	0.040	0.037	0.029
Cu	6.02	< 0.1	3.45	< 0.1	4.02	< 0.1
Fe	19.5	1.8	20.5	< 0.1	32.0	6.2
K	29,459	379	26,675	125	68,794	426
Li	0.041	0.115	0.207	0.156	0.092	0.120
Mg	1,337	1,176	1,329	2,143	1,278	1,245
Mn	8.43	143	10.04	85.1	6.80	26.3
Na	307	89	349	61	538	325
Ni	0.320	0.28	0.285	0.378	0.374	0.15
P	2 888	178	3 076	66		
Pb	0.025	0.04	0.013	0.12	< 0.001	0.02
S	1,712	70	1,516	190		
Sr	2.79	65.1	1.12	72	1.02	19
Zn	21.2	7.1	12.6	2.2	32.4	87.3

Table 6 Varieties and respective sites of growth.

Zinsenhof	Schönbrunn	Donaustadt
Aroma	Bonaparte	Saloniki
Buffalo I	Buffalo II	schlesische Himbeere
Favorita	Goldita	
Gourmandia	Mercedes	
Marmyto	Olivade	
Ruthje	Sungold	
	Sweet Million	
	Tigerella	

Tomatoes randomly collected at Turkish markets (80 samples) contained about 4 times more Na, but just 1/3 of Ca, compared with samples of this work. This might be due to high salinity water used for irrigation. Principal component analysis revealed relations between Mn-Mo and Ca-Zn like in this work, but relations P-K and Fe-Mg and Ca-Na obtained in Turkish samples were not found here [17]. Soil type, varieties, climate and fertilization methods might largely influence these interelement relationships. Highly significant differences between the contents of fresh tomatoes and tomato-based products were found for Na, P, Ca, Cu, Zn and Mo, but none for K, Mg, Fe, Mn and Se [17].

Data from tomato variety Aromata grown in Denmark either hydroponically or in inert rockwool slabs, approached about the levels met in this work, in case of Ca, Mg, Zn, Cd, Pb, Mo, and V. They were some lower for Fe, K, Na, and Ni, and some higher for P, S, Cu, Mn, and Sr [11]. Principal component analysis also primarily reflected differences in growth medium soil or inert rockwool slabs, when first (Na-Mn-Mo-(-Ca)-(-Cd)-(-Sr)) and second (K-Mg-P-S) components were plotted against each other [11].

Tomatoes grown on tropical soils in Thailand contained significantly less Ca, Mg, K, Na, and even Si than the tomatoes analyzed for this work, whereas the essential trace elements Fe, Zn, Mn and Cu were found at the same levels [15].

3.5 Tomatoes in Human Nutrition

In order to maintain adequate supply in human nutrition, for some essential elements a daily intake has been recommended (RDI) by a joint commission of Germany, Austria and Switzerland (DACh-values), which are indicated in Table 1 in addition to the data obtained within this project. It can be seen that consumption of 1 kg fresh tomatoes cannot cope with needs of trace element human nutrition. But the merits of tomatoes are due to lycopin and other anti-oxidants, which have not been determined within this project.

Hazardous metal levels in fresh weight were far below threshold limits, like 3 ± 1 μg/kg for Cd (limit is 50 μg/kg, or 7 μg/kg body weight and week), and lead 2 ± 2 μg/kg (limit is 100 μg/kg, or 25 μg/kg body weight and week) [18]. In addition, average Cr (2 μg/kg) and Ni (20 μg/kg) was also quite negligible with respect to daily intake budgets.

Within Table 7, data of this work have been compiled with respective data from references, with respect to tomatoes grown on soil, in descending concentrations per dry mass.

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Table 7 Comparison of data of this work with references, conventionally grown on soil, mg/kg dry mass.

			Demirbas	Rodriguez-Iruretagoiena et al.		Krug, Liebig, Stützel			Kelly, Bateman	Taharn et al.		Bressy et al.	
This work	This work		Turkey	Spain		Spain		Switzerland	England	Thailand		Brazil	
Mean ± std.dev	various		various	various	cherry	round	big size	round	various	7 varieties	cherry	round	big size
31,980 ± 16,140	27,885	K	16,590-20,810						35,000	91-205			
1,584 ± 501	1,456	Ca	2,880-3,540		794	1,125	2,101	2,396	1,000	177-395			
1 253 ± 270	1,242	Mg	4,220-6,320		1,925	1,197	2,636	1,363	1,800	118-217			
327 ± 147	306	Na	5,570-7,180		816	308	238	163	800	46-139			
21.9 ± 15.1	17.1	Si								2.61-3.08			
19.3 ± 8.0	17.4	Fe	1.98-2.41	19-80					40	22.2-43.3	43.8	43.1	47.9
17.6 ± 8.0	17.3	Zn	65-76	14-30	15	13	18	26	26	15.7-46.9	19.7	29.5	22.3
7.99 ± 2.40	8.05	Mn		5.8-23	13	25	18	7	17	7.68-19.0	5.64	18.2	13.3
5.95 ± 3.48	4.64	*Rb*			16	5	5	7	5				
4.15 ± 1.61	3.99	Cu	12.9-18.7	5.4-28.6	8	4	4.5	10	6	2.93-8.68	5.40	5.13	9.19
1.90 ± 1.06	1.81	Sr			4	5	24	9	8		9.3	2.66	11.9
1.39 ± 0.81	1.09	Al		< -15.3	< 0.01	0.5	0.2	2.1		0.06-0.68	57.8	36.6	39.2
0.48 ± 0.23	0.45	Ba			0.2	0.2	1.1	1.4		0.062-0.092			
0.466 ± 0.096	0.45	Mo			0.7	0.8	0.8	0.9		0.05-0.37			
0.290 ± 0.134	0.247	Ni		0.11-1.02	0.4	0.2	2.3	1.0		0.09-0.36	0.55	0,775	0,63
0.127 ± 0.097	0.076	Li			0.5	0.1	0.1	0.2					
0.034 ± 0.046	0.042	Cr		0.42-1.80						0.35-0.62	0.25	0.395	0.26
0.045 ± 0.021	0.037	Cd	0.61-0.71	0.048-0.31	0.04	0.07	0.03	0.09			0.008	0.21	0.0092
0.018 ± 0.007	0.018	Co		0.032-0.177	0.03	0.09	0.13	0.09			1.36	4.39	0.634
< 0.001 – 0.042	0.015	Pb	0.38-0.48	0.041-0.147	< 0.01	0.19	< 0.01	0.17		0.09-0.26			
< 0.05	< 0.05	V		0.14-0.61							0.16	0.325	0.42