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Effects of crop system and genotype on yield, quality, antioxidants and chemical composition of organically grown leek

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Abstract: The research was carried out in order to assess the effects of nine cultivars in factorial combination with open field or greenhouse growing on yield, quality indicators, antioxidants and elemental composition of leek in Moscow region. Greenhouse management resulted in higher yield compared to open field cultivation, due to higher mean pseudo-stem weight, and cultivar Giraffe gave the highest production. Pseudo-stem dry matter was better affected by greenhouse cultivation, whereas the content of monosaccharides, total sugars, nitrates, ascorbic acid and polyphenols was enhanced by open field growing. The cultivars Vesta and Summer breeze showed the highest dry matter and total sugar content, whereas Goliath had the highest antioxidant, selenium and potassium concentration. Among the mineral elements, K and Mg in pseudo-stems were better affected by greenhouse conditions, whereas Ca attained a higher concentration under open field growing. The antioxidant system of *Allium porrum* was characterized by significant positive correlations between Se, polyphenols, ascorbic acid and potassium.

1. Introduction

Leek (*Allium porrum* L.) is a major crop among *Allium* species and it is mainly grown in Indonesia, Turkey and, within Europe, in France and Belgium for producing edible pseudo-stems. The latter have high nutritional value, also due to the high content of potassium and iron (Koca and Tasci, 2016), and high biological activities connected with the remarkable concentration of antioxidants comparable with that of *Allium cepa*

(Sekara *et al.*, 2017), such as polyphenols (Ben Arfa *et al.*, 2015), glucosinolates, S-alkenyl-L-cysteine sulfoxides and pectic polysaccharides (Ozgur *et al.*, 2011). Accordingly, leek shows antimicrobial, cardio-protective, hypo-cholesteremic, hypoglycemic, anti-rheumatic, hypotensive, antianemia, and anticancer action, improves liver, gastro-intestinal and brain efficiency, decreases blood pressure, inhibits platelets aggregation and prevents neural tube defects as well as prostate diseases (Radovanović *et al.*, 2015).

Protected cultivation may be appropriate to organic horticulture which is more susceptible to the environmental unbalances due to the milder farming practices and is usually more profitable than the conventional management (Caruso *et al.*, 2012; Conti *et al.*, 2015). Within the crop system, cultivar assessment in terms of content of antioxidants as well as macro- and micro-elements in leek pseudo-stems raises the interest of establishing the relations between the mentioned substances and, accordingly, identifying the most interesting genotypes, also based on their yield. Due to the fragmented investigations relevant to varietal differences in biologically active compounds (Bernaert *et al.*, 2012) and elemental composition (Koca and Tasci, 2016), we carried out research aiming to evaluate the effect of both crop system and cultivar on yield, quality, antioxidant content and elemental composition of *A. porrum* grown either in greenhouse or in open field.

2. Materials and Methods

Plant material and growth conditions

Research was carried out on leek (*A. porrum* L.) grown in greenhouse at the experimental fields of Federal Scientific Center of Vegetable Production, in Odintsovo (Moscow, Russia, 55°40' N, 37°12' E) in 2015 and 2016 on a clay-loam soil, with pH 6.8, 2.1% organic matter, 108 mg kg^{-1} N, 450 mg kg^{-1} P_2O_5, 357 mg kg^{-1} K_2O, exchangeable bases sum as much as 95.2%. Mean temperature values from May to October were: 13.0, 16.1, 19.8, 18.6, 12.3, 6.4°C in open field; 20.4, 21.4, 23.7, 20.0, 14.5, 8.3 in greenhouse. The experimental protocol was based on the factorial combination between two crop systems (open field, greenhouse) and nine cultivars (Goliath, Summer breeze, Premier, Casimir, Kalambus, Camus, Vesta, Giraffe, Bandit), using a split-plot design with three replicates.

The sowing was performed on 5 December in 8 x 8 cm trays and the plantlets were transplanted in the field on 14 May, spaced 15 cm along the rows, the latter being 40 cm apart. Leek crops were preceded by organically grown vegetables in the previous four years, such as carrot, bean, rape and pea. Prior to planting, plough at 30 cm depth, hoeing at 15 cm and fertilization with 180 kg ha^{-1} N, 80 P_2O_5 and 120 K_2O were practiced; during the growing period, 40 kg ha^{-1} N were supplied in three times at two-week intervals, starting at bulbification stage, and just in the last N application 7 kg ha^{-1} of P_2O_5 and of K_2O were also provided. Drip irrigation was activated at 80% soil available water. The organic farming practice complied with EC Regulation 834/2007 and 889/2008. Plant protection was achieved by applying copper oxychloride against rust and azadirachtin against aphids.

Harvests of ripe plants were performed from 5 to 10 October in greenhouse and from 12 to 19 October in open field, when the pseudo-stems had reached their maximum growth, and the leaf blades were trimmed at 15 cm length for obtaining the marketable product. In each plot, determinations were made of the marketable product weight (pseudo-stems with 15 cm long leaf blades) and the mean pseudo-stem (with 15 cm long leaf blades) weight on twenty-plant samples. Further plant samples were collected, gently washed with water to remove surface contaminants and dried with filter paper. Pseudo-stems and leaves were separated, cut with plastic knife, dried to constant weight and homogenized; the resulting powders were subjected to laboratory analysis.

Dry matter

The dry matter content in leaves and pseudo-stems of *A. porrum* was assessed after dehydration of the fresh samples in an oven at 70°C, until they reached constant weight.

Sugars

Monosaccharides were determined using ferricyanide colorimetric method, based on the reaction of monosaccharides with potassium ferricyanide (Swamy, 2008). Total sugars were determined after acidic hydrolysis of water extracts with 20% hydrochloric acid (Swamy, 2008). Fructose was used as an external standard.

Polyphenols

The concentrations of the total polyphenols in each sample of leaves and pseudo-stems were determined in 70% ethanol extract (1 hour at 80°C) using the Folin-Ciocalteu colorimetric method, according to

Golubkina *et al.* (2018 b) by Unico 2804 UV (USA) spectrophotometer. The polyphenol content was expressed as milligrams of gallic acid equivalents per 100 grams of dry weight (mg GAE 100 g^{-1} d.w.).

Ascorbic acid

The ascorbic acid content in leek leaves and pseudo-stems was assessed by visual titration of fresh plant extracts in 6% trichloracetic acid with Tillmans reagent (Caruso *et al.*, 2009; AOAC, 2012).

Antioxidant activity

The antioxidant activity of leek leaves and pseudo-stems was assessed using redox titration method (Maximova *et al.*, 2001; Golubkina *et al.*, 2018 b), via titration of 0.01 N $KMnO_4$ solution with ethanolic extracts of leaves and pseudo-stems. The values were expressed in mg GAE 100 g^{-1} d.w.

Nitrates

The nitrate content was assessed in fresh pseudo-stems using ion selective electrode on ionomer Expert-001 (Econix, Russia).

Elemental composition

The content of Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, I, K, Li, Mg, Mn, Na, Ni, P, Pb, Se, Si, Sr, V and Zn in leek pseudo-stems was assessed using ICP-MS on quadruple mass-spectrometer Nexion 300D (Perkin Elmer Inc., Shelton, CT 06484, USA) in the Biotic Medicine Center in Moscow (Golubkina *et al.*, 2017).

Statistical analysis

Data were processed by analysis of variance and mean separations were performed through the Duncan multiple range test, with reference to 0.05 probability level, using SPSS software version 21. The data expressed as a percentage were subjected to angular transformation before processing.

As the year of research had no significant effect on the yield, quality, antioxidant and elemental composition variables examined, both as main factor or in interaction with the experimental factors "crop system" and "cultivar", the results are reported as average values of the two years of investigation.

3. Results and Discussion

Growth, yield and quality indicators of pseudo-stems

The crop system showed significant effects on leek plant biomass, pseudo-stem yield and mean weight, as these variables attained higher values in greenhouse compared to open field (Table 1); as reported in the previous section, the plant commercial ripeness was anticipated by 8 days on average in the protected environment. These trends are consistent with those recorded in previous research (Conti *et al.*, 2015). Differences between the varieties were recorded with regard to: biomass, which was highest in cultivar Summer breeze and lowest in Premier; mean pseudo-stem weight and, accordingly, yield which ranged from 22.0 to 36.1 Mg ha^{-1}, with the cultivar Giraffe showing the best performance, Premier and Kalambus the worst.

The greenhouse growing resulted in higher concentration of dry matter, ash and nitrates, but lower monosaccharides and total sugars in pseudo-stems, compared to those detected in open field (Table 1), similarly to previous reports (Conti *et al.*, 2015). Notably, the values of dry matter recorded in our

Table 1 - Growth and yield indicators, and content of dry matter, sugars and nitrates in *A. porrum* pseudo-stems

Treatment	Plant biomass (Kg m^{-2} d.w.)	Marketable pseudo-stems						
		Yield (Mg ha^{-1})	Mean weight (g)	Dry matter (%)	Monosaccharides (g 100 g^{-1} d.w.)	Total sugars (g 100 g^{-1} d.w.)	Ash (%)	Nitrates (mg kg^{-1} f.w.)
Crop system								
Open field	11.0	25.3	162.8	16.7	3.81	12.0	4.8	44.7
Greenhouse	15.8	30.8	185.7	19.7	3.41	10.7	5.2	66.3
	*	*	*	*	*	*	*	*
Cultivar								
Goliath	8.7 ef	27.6 de	177.0 de	12.1 e	5.11 a	7.5 e	8.5 b	48.0 d
Premier	8.3 f	22.0 g	132.6 g	14.6 d	4.62 ab	10.6 c	12.4 a	45.9 d
Bandit	12.0 d	31.0 bc	192.8 bc	14.9 d	3.73 c	8.9 d	4.7 c	65.3 a
Kalambus	9.9 e	22.3 g	134.6 g	17.1 c	4.13 bc	10.5 c	2.8 e	43.1 d
Cazimir	11.6 d	24.3 f	150.1 f	18.4 c	2.98 d	11.0 bc	4.1 cd	57.5 bc
Giraffe	18.6 b	36.1 a	225.4 a	19.8 b	3.58 c	11.2 bc	3.1 e	54.7 c
Camus	16.0 c	29.9 cd	188.0 cd	20.6 b	2.62 d	12.3 b	3.2 e	64.9 a
Vesta	15.4 c	26.3 ef	163.8 ef	22.6 a	2.74 d	14.6 a	2.9 e	60.1 ab
Summer breeze	20.3 a	33.1 b	204.5 b	23.7 a	2.97 d	15.5 a	3.4 de	60.5 ab

* significant at P≤0.05. Within each column, means followed by different letters are significantly different according to Duncan test at P≤0.05.

research fell within the 12.1 to 23.7 % range (Table 1) which is much wider than that relevant to *A. porrum* grown in Czech Republic (9-11%) (Lundegardh *et al.*, 2008). Moreover, the cultivars with high dry matter content (Summer breeze and Vesta) have a long shelf-life and are even suitable as dry spice source, whereas the varieties showing low dry matter (Goliath, Premier and Bandit) better fit the salad industry target.

Significant varietal differences in ash content were recorded (Table 2), with the ratio between leaf and pseudo-stem related to this variable decreasing as follows: Summer breeze > Cazimir > Vesta > Giraffe > Bandit > Kalambus > Camus > Premier > Goliath.

The higher nitrate accumulation in pseudo-stems grown in greenhouse is connected with the lower light intensity occurring in the protected environment compared to open field conditions, which limits the nitrate reductase activity; however, it was much lower (105 mg kg^{-1} f.w.) than that relevant to the top-accumulator species (Caruso *et al.*, 2011) and referred to previous reports (Santamaria, 2006).

Antioxidants

Ascorbic acid and polyphenols highly affect plant antioxidant activity (Proteggente *et al.*, 2002); in our research, the open field conditions resulted in higher content of both antioxidant compounds in leek pseudo-stems compared to greenhouse (Table 2). The crop system did not affect the selenium concentration either in pseudo-stems or leaves of *A. porrum*.

The high average content of ascorbic acid recorded in our research presumably makes the product safe and healthy, as ascorbic acid participates in producing essential nitrogen oxide for human organism, thus preventing nitrosamine formation from nitrate accumulating in plants (Santamaria, 2006). Moreover, wide varietal differences were found in ascorbic acid concentration, unlike the polyphenol content which was characterized by higher stability in pseudo-stems and even more in leaves (Table 2). Among the cultivars examined, Goliath showed the highest content of ascorbic acid, polyphenols and selenium in pseudo-stems (Table 2). Notably, these cultivars from domestic selection are characterized by lower levels of polyphenols compared to literature references, which may be connected with the different crop cycle and harvest time (Biesiada *et al.*, 2007). Bernaert *et al.* (2012) also reported a higher polyphenol concentration in pseudo-stems of thirty leek cultivars grown in Belgium (7.3 to 11.3 mg GA g^{-1} d.w.) compared to our values (3.3 to 6.3), but a lower content of ascorbic acid ranging between 90 to 350 mg 100 g^{-1} d.w.

In the latter research no correlation was recorded between ascorbic acid and polyphenol concentration in leek pseudo-stems, whereas a significant positive relationship has been found in our investigation ($r = 0.94$ at $P<0.01$). The lack of correlation relevant to the thirty leek cultivars grown in Belgium (Bernaert *et al.*, 2012) presumably depends on varietal hetero-

Table 2 - Concentrations of ascorbic acid, polyphenols and selenium in leek

Treatment	Ascorbic acid in pseudo-stems (mg 100 g^{-1} f.w.)	Polyphenols (mg GA 100 g^{-1} d.w.)		Selenium (µg kg^{-1} d.w.)	
		Pseudo-stems	Leaves	Pseudo-stems	Leaves
Crop system					
Open field	57.6	466.5	887.1	71.9	61.2
Greenhouse	47.2	376.8	699.5	76.2	64.4
	*	*	*	NS	NS
Cultivar					
Goliath	169.3 a	626.1 a	827.8 a	106.4a	14.1 e
Premier	72 b	497.6 b	751.8 b	79.1 b	64.8 c
Bandit	50.6 c	455.6 bc	739.8 b	74.1 bc	47.2 d
Kalambus	32.1 de	368.6 de	858.5 a	70.6 bc	74.8 b
Cazimir	37 d	334.1 e	843.1 a	59.7 e	76.9 ab
Giraffe	31.3 ef	386.1 d	760.8 ab	72.9 bc	48.4 d
Camus	27.1 fg	401.6 cd	786.3 ab	63.1 de	81.4 ab
Vesta	24.3 g	345.3 de	855.5 a	68.1 cd	85.4 a
Summer breeze	28.0 fg	379.7 de	716.3 b	72.1 bc	72.3 bc

NS not significant; * significant at $P\leq0.05$. Within each column, means followed by different letters are significantly different according to Duncan test at $P\leq0.05$.

geneity, consequent to genotype selection based on morphological types (light-green summer type, dark-green winter type and intermediate autumn type).

Interestingly, in our research the concentration of polyphenols in leek leaves has always been higher than the pseudo-stem one, raising the issue of possible crop waste valorization as a source of these antioxidants.

Among the components of plant antioxidant system, selenium also plays a significant role. Indeed, though it is not an essential element for plants, selenium is able to provide a powerful antioxidant defense to plants against drought, salinity, frost, flooding, UV light and herbivore (Malagoli *et al.*, 2015). Notably, *Allium* species belong to the secondary selenium accumulators, which show a remarkable tolerance to high concentration and consequent accumulation of this element due to Se ability to substitute sulfur in natural compounds, as previously reported in leek (Koca and Tasci, 2016).

In our research, *A. porrum* grown in Moscow region showed a Se accumulation range from 60 to 107 µg kg^{-1} d.w., which is much lower than the values recorded in Turkey (Koca and Tasci, 2016). This suggests the significant effect of selenium status in the environment on plant ability to concentrate this microelement. The adverse correlation between selenium content in leaves and pseudo-stems (r= - 0.95 at P≤0.01), similar to that recorded for polyphenols, entails a rather stable level of selenium accumulation in plant.

Reports relevant to selenium in plant secondary metabolites, as well as to polyphenols particularly in absence of selenium uptake are rather scarce and often controversial. In this respect, a positive correlation between selenium and polyphenol content was found in wheat (Lachman *et al.*, 2011) and a negative correlation between quercetin and selenium was recorded in *A. cepa* (Golubkina *et al.*, 2016). However, moderate doses of selenium are deemed to enhance the content of antioxidants such as polyphenols, flavonoids and carotenoids (Malagoli *et al.*, 2015).

In our research, the nine leek genotypes examined showed significant correlations between the components of the antioxidant system, i.e. selenium, ascorbic acid and polyphenols: Se and ascorbic acid (r= 0.93 at P≤0.01); Se and polyphenols (r= 0.92 at P≤0.01); ascorbic acid and polyphenols (r = 0.94 at P≤0.01). The latter correlations relevant to leek pseudo-stems may be significantly useful in leek selection based on high antioxidant content.

Elemental composition

The beneficial effect of many mineral elements to human health has arisen a remarkable interest to the chemical composition of vegetable crops, such as leek (Koca and Tasci, 2016). Investigations of element content in *A. porrum* plants have disclosed this species ability to accumulate high concentrations of minerals, but so far assessments of the leek whole profile relevant to mineral elements and to the varietal features connected to their accumulation have been lacking.

The analysis of twenty-five element content in leek pseudo-stems (Tables 3-5) has allowed to assess the varietal differences in elemental profile. The concentration of calcium was higher in pseudo-stems grown in greenhouse, whereas potassium and magnesium attained higher levels in open field. Sodium,

Table 3 - Macroelement concentration in *A. porrum* pseudo-stems (g kg^{-1} d.w.)

Treatment	Calcium	Potassium	Magnesium	Sodium	Phosphorus
Crop system					
Open field	4.2	22.5	1.0	0.27	2.83
Greenhouse	4.8	18.9	0.8	0.28	2.73
	*	*	*	NS	NS
Cultivar					
Goliath	3.7 bc	58.7 a	0.8 c	0.32 bc	3.12 b
Premier	3.1 cd	5.4 e	0.8 c	0.36 b	2.74 bc
Bandit	10.4 a	26.3 b	2.1 a	0.75 a	2.53 cd
Kalambus	4.0 b	15.2 c	0.6 d	0.16 e	2.43 cd
Cazimir	4.3 b	9.0 d	0.6 d	0.15 e	2.08 d
Giraffe	2.6 d	17.9 c	0.7 cd	0.12 e	2.49 cd
Camus	4.4 b	19.6 c	1.1 b	0.16 e	4.07 a
Vesta	3.9 bc	16.9 c	0.7 cd	0.18 de	2.77 bc
Summer breeze	4.4 b	17.7 c	0.8 c	0.26 cd	2.80 bc

NS not significant; * significant at P≤0.05. Within each column, means followed by different letters are significantly different according to Duncan test at P≤0.05.

phosphorus and all the microelements and heavy metals analyzed were not significantly affected by the crop system (Tables 3-5). Moreover, the potassium concentration was positively correlated with the ash content (r= 0.78 at P≤0.01).

From the comparison between the nine leek cultivars it arose that the three cultivars Premier, Goliath and Cazimir had contrasting features from each other. Indeed, Goliath was characterized by the highest content of K, Fe, B, Zn and Se, and the lowest of Cd. Premier accumulated preferably Co, I, Al, As, Cd, Ni, Pb and Sr, but poorly Cu and Zn. Cazimir showed the highest concentration of Na and Zn, but the lowest of K, I, Se, Cr and Ni.

Among the minerals examined, the highest correlation coefficients were recorded between Al and As, Pb, V, Co and Li. Indeed, the physiological role of Al in plants has not been completely understood so far, though this element is supposed to both activate at low doses some enzymes and control membrane permeability (Ahn and Matsumoto, 2006).

Lithium also showed wide varietal differences, consistently with previous reports (Kabata-Pendias and Pendias, 2010). The correlations recorded in our research are in agreement with those found in five species grown both in ecological unpolluted and in oil-polluted areas of Nigeria (Essiett *et al.*, 2010). As for selenium, though the leek varietal differences are rather low compared to other elements, the significant correlation recorded between Se and K is a remarkable characteristic of this *Allium* species and it has been very scarcely investigated so far.

In spinach, the fertilization with sodium selenate increased the potassium content in the female plants but not in the male ones (Golubkina *et al.*, 2017), whereas in other research (Põldma *et al.*, 2011) garlic biofortification led to selenium antagonistic activity towards K. Taking into account that potassium participates in plant protection against all forms of biotic and abiotic stress along with selenium and other antioxidant compounds (Wang *et al.*, 2013), the close relationship between the two minerals in leek suggests intensive interactions between all components of the defense system. Indeed, potassium was predominant in leek elemental composition, showing significant correlations with both ash (r= 0.78 at P≤0.01) and polyphenols (r= 0.96 at P≤0.01). The known ability of potassium to decrease the activity of polyphenol oxidase in plants and enhance polyphenol accumulation (Mudau *et al.*, 2007) may be a good explanation of the positive correlation between polyphenols and potassium in leek plants. The active

Table 4 - Microelements concentration in *A. porrum* pseudo-stems (mg kg^{-1} d.w.)

Element	Goliath	Cazimir	Premier	Vesta	Kalambus	Summer breeze	Bandit	Giraffe	Camus
B	20.5 a	14.8 bc	16.3 b	9.5 de	8.5 e	9.4 de	9.4 de	12.3 cd	10.7 d
Co	0.08 b	0.05 d	0.10 b	0.03 d	0.29 a	0.04 d	0.04 d	0.04 d	0.10 b
Cu	4.7 df	4.4 ef	3.4 g	5.7 bc	6.4 ab	5.0 ce	6.8 a	4.0 fg	5.3 cd
Fe	206 a	110 c	168 b	97 bd	74 e	80 de	93 ce	100 cd	215 a
I	0.06 bc	0.04 c	0.31 a	0.04 c	0.06 bc	0.06 bc	0.04 c	0.08 b	0.08 b
Li	0.11 b	0.04 c	0.15 a	0.03 c	0.01 c	0.03 c	0.02 c	0.03 c	0.11 b
Mn	12.2 c	12.0 c	22.6 a	9.8 c	6.3 d	9.5 c	10.6 c	19.2 b	21.7 ab
Si	14.1c	10.5 d	27.3 a	9.2 e	12.8 cd	13.1 cd	11.0 de	18.8 b	15.4 c
Sn	0.15 c	0.22 b	0.02 d	0.16 c	0.48 a	0.18 bc	0.51 a	0.22 b	0.23 b
Zn	23.5 ab	26.7 a	11.8 f	18.1 de	16.0 e	19.2 ce	21.5 bc	22.2 bc	21.2 bd

Within each row, means followed by different letters are significantly different according to Duncan test at P≤0.05.

Table 5 - Heavy metal concentration in *A. porrum* pseudo-stems (mg kg^{-1} d.w.)

Element	Goliath	Cazimir	Premier	Vesta	Kalambus	Summer breeze	Bandit	Giraffe	Camus
Al	78.0 c	29.5 d	126.0 a	21.0 df	7.7 g	24.1 de	12.2 fg	19.3 ef	88.4 b
As	0.03 b	0.02 bc	0.05 a	0.02 bc	0.01 c	0.02 bc	0.01 c	0.02 bc	0.06 a
Cd	0.08 d	0.10 bc	0.18 a	0.11 b	0.08 d	0.06 d	0.11 b	0.17 a	0.11 b
Cr	0.13 c	0.08 g	0.48 a	0.10 df	0.10 eg	0.12 cd	0.09 fg	0.15 b	0.11 ce
Ni	1.05 a	0.46 c	0.96 ab	0.98 ab	0.56 c	0.57 c	0.83 b	0.60 c	1.08 a
Pb	0.34 b	0.28 bc	0.83 a	0.10 e	0.10 e	0.13 de	0.20 cd	0.12 e	0.83 a
Sr	28.3 ab	25.3 c	30.4 a	24.6 c	28.2 ab	17.3 d	28.8 ab	26.4 bc	28.5 ab
V	0.21 b	0.07 cd	0.28 a	0.07 cd	0.04 d	0.09 c	0.07 cd	0.07 cd	0.30 a

Within each row, means followed by different letters are significantly different according to Duncan test at P≤0.05.

participation of potassium in the antioxidant defense system of this *Allium* species is also characterized by positive correlation of the element with the ascorbic acid content (r= 0.95 at P≤0.01). In this respect, the results of the present work reveal the close relationship between the main components of the leek antioxidant system, including polyphenols, ascorbic acid, selenium and potassium.

In our research, the lowest negative correlation coefficients were recorded between selenium, chromium and iodine (Table 6). Se is known as an antagonist of Cr and its protective role towards Cr has been previously reported (Qing *et al.*, 2015). The interaction between Se and I is more complex; both the elements are not essential for plants, but at low concentrations they may improve plant growth, development and protection from biotic and abiotic stresses (Pilon-Smits, 2015). Separate plant fortification with Se and I showed the possibility of mutual stimulation by the two elements (Golubkina *et al.*, 2018 a). The selective accumulation of selenium in the spinach male plants and of iodine in the female ones suggests the participation of phytohormones in the interactions between selenium and iodine (Golubkina *et al.*, 2017).

With regard to heavy metals, highly significant correlations were found between V and Al, As, Co, Pb and Fe (Table 6).

4. Conclusions

From research carried out in Moscow region with the aim to assess the effects of open field or greenhouse conditions on yield and quality performances of nine leek (*A. porrum*) cultivars under organic farming, useful remarks have been drawn. The genotypes examined had a uniform behavior with both the crop systems, showing higher yield and dry matter when grown in the protected environment, but better quality and antioxidant performances in the open field conditions. Taking into account that Giraffe was the highest-yielding cultivar, whereas Goliath displayed the best overall quality and antioxidant features, the identification of best-performing genotypes within a crop system is target dependent.

References

AHN S.J., MATSUMOTO H., 2006 - *The role of the plasma membrane in the response of plant roots to aluminum toxicity*. - Plant Signal Behav., 1: 37-45.

AOAC, 2012 - *The official methods of analysis of AOAC. 22 Vitamin C*. - Association Official Analytical Chemists, AOAC International, USA.

BEN ARFA A., NAJJAA H., YAHIA B., TLIG A., NEFFATI M., 2015 - *Antioxidant capacity and phenolic composition as a function of genetic diversity of wild Tunisian leek (*Allium ampeloprasum *L.)*. - Acad. J. Biotechnol., 3: 15-26.

BERNAERT N., DE PAEPE D., BOUTEN C., DE CLERCQ H., STEWART D., VAN BOCKSTAELE E., DE LOOSE M., VAN DROOGENBROECK B., 2012 - *Antioxidant capacity, total phenolic and ascorbate content as a function of the genetic diversity of leek (*Allium ampeloprasum *var.* porrum*)*. - Food Chem., 134: 669-677.

BIESIADA A., KOLOTA E., ADAMCZEWSKA-SOWINSKA K., 2007 - *The effect of maturity stage on nutritional value of leek, zucchini and kohlrabi.* - Vegetable Crops Res. Bull., 66: 39-45.

CARUSO G., CONTI S., LA ROCCA G., 2011 - *Influence of crop cycle and nitrogen fertilizer form on yield and nitrate content in different species of vegetables*. - Adv. Hort. Sci., 25(2): 81-89.

CARUSO G., VILLARI G., BORRELLI C., RUSSO G., 2012 - *Effects of crop method and harvest seasons on yield and quality of green asparagus under tunnel in southern Italy*. - Adv. Hort. Sci., 26(2): 51-58.

CARUSO G., VILLARI G., RUSSO G., 2009 - *Influence of cover type and training method on yield and quality of "organic" muskmelon*. - Adv. Hort. Sci., 23(1): 3-7.

CONTI S., VILLARI G., AMICO E., CARUSO G., 2015 - *Effects*

Table 6 - Correlation coefficients between mineral elements in *A. porrum* pseudo-stems

	As	Ca	Co	Cr	Fe	I	K	Li	Mg	Mn	Pb	V
Al	0.93 ***	0.71 *	0.95 ***	0.74 *	0.85 **	0.77 **	0.50	0.99 ***	0.75 *	0.74 *	0.92 ***	0.98 ***
K	0.23	0.13	0.39	0.21	0.63	0.17	1.00					
Li	0.90 ***	0.70 *	0.93 ***	0.73 *	0.86 **	0.76 *	0.56	1.00				
Se	0.05	0.14	0.19	-0.72 *	0.42	-0.71 *	0.95 ***	0.42	0.18	-0.03	0.04	
V	0.94 ***	0.60	0.98 ***	0.61	0.91 ***	0.65	0.51	0.97 ***	0.64	0.75 *	0.94 ***	

*** P≤0.001; ** P≤0.01; * P≤0.05.

*of production system and transplanting time on yield, quality and antioxidant content of organic winter squash (*Cucurbita moschata *Duch.)*. - Sci. Hortic., 183: 136-143.

ESSIETT U.A., EFFIONG G.S., OGBEMUDIA F.O., BRUNO E.J., 2010 - *Heavy metal concentrations in plants growing in crude oil contaminated soil in Akwa Ibom State, South-Eastern Nigeria*. - Afr. J. Pharmacol., 4: 465-470.

GOLUBKINA N., KEKINA H., CARUSO G., 2018 a - *Foliar biofortification of Indian mustard (*Brassica juncea *L.) with selenium and iodine.* - Plants, 7: 80.

GOLUBKINA N.A., KEKINA H.G., ANTOSHKINA M.S., AGAFONOV A.F., NADEZHKIN S.M., 2016 - *Intervarietal differences in accumulation of biologically active compounds by* Allium cepa *L*. - Mess. Russ. Agric. Sci., 2: 51-55.

GOLUBKINA N.A., KEKINA H.G., MOLCHANOVA A.V., ANTOSHKINA M.S., NADEZHKIN S.M., SOLDATENKO A.V., 2018 b - *Plants antioxidants and methods of their determination*. - VNIISSOK, Moscow (in Russian).

GOLUBKINA N.A., KOSHELEVA O.V., KRIVENKOV L.V., NADEZHKIN S.M., DOBRUTSKAYA H.G., CARUSO G., 2017 - *Intersexual differences in plant growth, yield, mineral composition and antioxidants of spinach (*Spinacia oleracea *L.) as affected by selenium form*. - Sci. Hortic., 225: 350-358.

KABATA-PENDIAS A., PENDIAS H., 2010 - *Trace elements in soils and plants*. - CRC Press, Boca Raton, Florida, USA, pp. 548.

KOCA I., TASCI B., 2016 - *Mineral composition of leek*. - Acta Horticulturae, 1143: 147-151.

LACHMAN J., MIHOLOVÁ D., PIVEC V., JÍRŮ K., JANOVSKÁ D., 2011 - *Content of phenolic antioxidants and selenium in grain of einkorn (*Triticum monococcum*), emmer (*Triticum dicoccum*) and spring wheat (*Triticum aestivum*) varieties*. - Plant, Soil Environ., 57: 235-243.

LUNDEGARDH B., BOTEK P., SCHULZO V., HAJŠLO V.J., STROMBERG V.A., ANDERSSON H.C., 2008 - *Impact of different green manures on the content of s-alk(en)yl-L-cysteine sulfoxides and L-ascorbic acid in leek (*Allium porrum*)*. - J. Agric. Food Chem., 56: 2102-2111.

MALAGOLI M., SCHIAVON M., DALL'ACQUA S., PILON-SMITS E.A.H., 2015 - *Effects of selenium biofortification on crop nutritional quality*. - Front. Plant Sci., 6: 280.

MAXIMOVA T.V., NIKULINA I.N., PAKHOMOV V.P., SHKARINA H.I., CHUMAKOVA Z.V., ARZAMASTSEV A.P., 2001 - *Method of antioxidant activity determination*. - RU Patent № 2.170,930.

MUDAU F.N., SOUNDY P., DU TOIT E.S., 2007 - *Effects of nitrogen, phosphorus, and potassium nutrition on total polyphenol content of bush tea (*Athrixia phylicoides *L.) leaves in shaded nursery environment*. - Hort. Sci., 42: 334-338.

OZGUR M., AKPINAR-BAYAZIY A., OZCAN T., AFOLAYAN A.J., 2011 - *Effect of dehydration on several physico-chemical properties and the antioxidant activity of leeks (*Allium porrum *L.)*. - Not. Bot. Hort. Agrobot. Cluj-Na., 39: 144-151.

PILON-SMITS E., 2015 - *Selenium in plants,* pp. 93-107. - In: LÜTTGE U., and W. BEYSCHLAG (eds.) *Progress in Botany 76*. Springer International Publishing, Basel, Switzerland, pp. 438.

PÕLDMA P., TÕNUTARE T., VIITAK A., LUIK A., MOOR U., 2011 - *Effect of Selenium treatment on mineral nutrition, bulb size, and antioxidant properties of garlic (*Allium sativum *L.)*. - J. Agric. Food Chem., 59: 5498-5503.

PROTEGGENTE A.R., PANNALA A.S., PAGANA G., VAN BUREN L., WAGNER E., WISEMAN S., 2002 - *The antioxidant activity of regularly consumed fruit and vegetables reflects their phenolic and vitamin C composition*. - Free Radic. Res., 36: 217-233.

QING X., ZHAO X., HU C., WANG P., ZHANG Y., ZHANG X., WANG P., SHI H., JIA F., QU C., 2015 - *Selenium alleviates chromium toxicity by preventing oxidative stress in cabbage (*Brassica campestris *L. ssp. Pekinensis*) *leaves*. - Ecotox., Environ. Safe., 114: 179-189.

RADOVANOVIĆ B., MLADENOVIĆ J., RADOVANOVIĆ A., PAVLOVIĆ R., NIKOLIĆ V., 2015 - *Phenolic composition, antioxidant, antimicrobial and cytotoxic activites of* Allium porrum *L. (Serbia) extracts*. - J. Food Nutr. Res., 3: 564-569.

SANTAMARIA P., 2006 - *Nitrates in vegetables: toxicity content, intake and EC regulation*. - J. Food Agric., 86: 10-17.

SEKARA A., POKLUDA R., DEL VACCHIO L., SOMMA S., CARUSO G., 2017 - *Interactions among genotype, environment and agronomic practices on production and quality of storage onion (*Allium cepa *L.). A review*. - Hort. Sci. (Prague), 44: 21-42.

SWAMY P.M., 2008 - *Laboratory manual on biotechnology*. - Rastogi Publications, Meerut, India, pp. 617.

WANG M., ZHENG Q., SHEN Q., GUO S., 2013 - *The critical role of potassium in plant stress response*. - Int. J. Mol. Sci., 14: 7370-7390.