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Genotypic effect on fruit production and quality, antioxidant content and elemental composition of organically grown *Physalis angulata* L. and *Physalis pubescens* L.

Nadezhda A. Golubkina[1], Helene G. Kekina[2], Mezar R. Engalichev[1], Marina S. Antoshkina[1], Gianluca Caruso[3]*

[1]Agrochemical Research Center, Federal Scientific Center of Vegetable Production
143080 Moscow Region, Odintsovo District, VNIISSOK, Selectsionnaya 14, Russia
[2] Medical Academy of Postgraduate Education, 123995 Moscow, Russia
[3] Department of Agricultural Sciences, University of Naples Federico II, Italy

ABSTRACT

Research was carried out in northern Europe (Russia) with the purpose of assessing the yield, quality, biologically active compounds and elemental composition of *Physalis angulata* and *Physalis pubescens* fruits. *P. angulata* cultivars 'Konditer' and 'Konditer 2' gave the highest yield and mean fruit weight (11.2 t ha^{-1} and 75 g, on average), whereas *P. pubescens* variety Zolotaya Rossip had the worst outcome as it produced the smallest berries (3 g). 'Zolotaya Rossip' fruits attained the highest values of dry matter and soluble solids, while 'Violet' and 'Korolek' the highest polyphenol and ascorbic acid concentrations, respectively. Organic acid composition of *Physalis* fruits revealed high varietal differences and predominant accumulation of tartaric and malic acids. Positive correlations were recorded between dry matter and polyphenols, as well as between Fe and Mn, but an adverse correlation between Si and Cd content. *Physalis* fruits showed to be a good source of beneficial compounds for human beings, such as polyphenols and ascorbic acid, as well as mineral nutrients, i.e. K, Mg, P, B, Co, Cu, Fe, Li, Mn, Si, V and Zn.

Keywords: mineral nutrients, organic acids, *Physalis angulata* L., *Physalis pubescens* L., polyphenols

INTRODUCTION

The possible approaches to identifying new functional food are concerned with the introduction of unconventional plants or with the use of crossbred crops, containing high concentrations of biologically active compounds. In this respect, the *Physalis* genus includes exotic species with wide biodiversity (Medina-Medrano et al., 2015), whose produce is exported to Europe from tropical and subtropical regions, mainly central-southern America, south-east Africa and Asia (Novoa et al., 2006). The demand for this produce is due to the high nutritional value and exclusive taste of the fruits (Puente et al., 2011), as well as to the medicinal properties of all plant parts, such as anti-asthma, anti-hepatitis, anti-malaria, anti-carcinogenic and cardio-protective activities (Sharma et al., 2015). Moreover, the high antioxidant activity of water and alcoholic extracts of *Physalis* plants is beneficial to patients suffering from Alzheimer's disease and dementia (Susanti et al., 2015).

Among the several *Physalis* species, *P. angulata* and *P. pubescens* are the most suitable for production

*Corresponding author.
e-mail: segolubkina45@gmail.com (N. Golubkina).

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in northern Europe due to their frost resistance and tolerance to fungal and bacterial diseases (Mamedov et al., 2017). Notably, genetic selection carried out in Russia has resulted in the creation of interesting varieties, mainly belonging to *P. angulata*, suitable for cultivation both in central Russia (Kondratieva and Engalichev, 2013; Mamedov et al., 2017) and in Siberia (Makarov, 2002). As for biological properties, wide ranges of antioxidant concentration in fresh *Physalis* fruits are reported in the literature, such as those of polyphenols from 2.5 to 934.9 mg GAE 100 g^{-1}, vitamin C from 18 to 929 mg 100 g^{-1} or carotenoids from 0.2 to 1074.7 mg 100 g^{-1} (Olivares-Tenorio et al., 2016).

Due to the scant literature concerned with *Physalis* fruit production and quality, in terms of both interspecies and varietal variability, the present research was aimed at evaluating the yield performance as well as fruit quality, elemental composition and antioxidant content of *P. angulata* and *P. pubescens* cultivars grown organically in northern Europe.

MATERIAL AND METHODS

Six *P. angulata* L. cultivars ('Violet', 'Lakomka', 'Konditer', 'Konditer 2', 'Lezhky', 'Korolek') and one cultivar of *P. pubescens* L. ('Zolotaya Rossip') were compared in a study carried out under organic farming management in the experimental fields of the Federal Scientific Center of Vegetable Production (Moscow Region, 55° 39' 23'' N, 37° 12' 43'' E) in 2015 and 2016. The trials were conducted on a clay-loam soil, with a pH of 6.8, 2.1% organic matter, 108 mg kg^{-1} N, 450 mg kg^{-1} P_2O_5, 357 mg kg^{-1} K_2O. The lowest and highest values of air temperature recorded at plant level were, in 2015 and 2016 respectively: 9.3 and 19.1, 8.5 and 18.5 in May; 11.6 and 22.2, 11.9 and 22.3 in June; 15.8 and 26.6, 15.2 and 25.7 in July; 13.4 and 25.3, 12.3 and 23.7 in August; 7.3 and 17.0, 7.2 and 17.2 in September. A randomized complete block design, with three replicates, was used for the distribution of treatments in the field; each treatment had a 19.25 m^2 (5.5 × 3.5 m) surface area and included 50 plants. Fifty-day-old *Physalis* seedlings had been obtained upon sowing in peat-filled polystyrene containers in a heated greenhouse; they were transplanted into the field on 23 May, spaced 55 cm along the rows, the latter being 70 cm apart. In Russia, the six *P. angulata* cultivars chosen for the trial are the most spread, whereas *P. pubescens* 'Zolotaya Rossip' is the only variety cultivated. The organic farming practice complied with EC Regulations 834/2007 and 889/2008 (Szeremeta et al., 2012). *Physalis* crops were preceded by pea, and each year the fertilization supplied the crops with 56 kg ha^{-1} of N, 16 of P_2O_5 and 98 of K_2O. Half of the fertilizer dose was given just before transplanting, and the remaining 50% by top dressing at two-week intervals. Drip irrigation was activated at 80% soil available water. Plant protection from fungal diseases and insects was performed by applying *Trichoderma* suspensions and products containing copper, sulphur, and azadirachtin. Harvests were carried out from mid-August to the end of September according to the following sequence expressed as days from planting: 'Zolotaya Rossip' – 85; 'Lakomka' – 90; 'Konditer 2' – 102; 'Violet' – 105; 'Korolek' – 108; 'Konditer' – 115; and 'Lezhky' – 118.

Ripe, undamaged and regularly shaped fruits were classified as "marketable". At every harvest, the weight, diameter and number of marketable fruits as well as the mean weight based on random samples of 50 fruits were assessed in each plot. Cumulative plant biomass was calculated as the sum of the above-ground plant biomass at the end of the experiment plus the total fruit production from the beginning of the harvest period. Dry weight was assessed after dehydration of the fresh samples in an oven at 70°C until they reached constant weight. In each plot, a sample of twenty-five fruits was collected and transferred to the laboratory for analysis.

Prior to analysis, *Physalis* fruits were extracted from the papery husk and homogenized with a stainless steel blender for 1 min. The resulting homogenates were immediately subjected to analysis. Determination of total soluble solids was carried out with a refractometer (IRF-22, Russia). The results were reported as °Brix at 20°C. Mono- and disaccharides were determined using the cyanide method (Kidin et al., 2008). The concentration of organic acids in *Physalis* fruits was determined using reverse phase HPLC (IPS, 2014), with a Shimadzu HPLC system, and appropriate standards of organic acids (Sigma-Aldrich). HPLC conditions were as follows: column: Supelcosil C18 25 mm × 6 mm; mobile phase: isocratic; 0.1 M freshly prepared K-phosphate buffer; pH 2.4; flow rate: 1 mL min^{-1}; oven temperature: 25°C; UV detection; wavelength: 254 nm; injection volume: 20 µL.

Total polyphenols and ascorbic acid content were assessed, as previously described (Golubkina et al., 2017), colorimetrically using Folin-Ciocalteu reagent with a Unico 2804 UV (USA) spectrophotometer and visual titration with Tillmans reagent. The elemental composition, i.e. Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, Hg, I, K, Li, Mg, Mn, Na, Ni, P, Pb, Se, Si, Sn, Sr, V and Zn contents in dried homogenized fruit samples and NO_3^- in fresh fruits of *Physalis* species were determined using ICP-MS with a Nexion 300D quadruple mass spectrometer (Perkin Elmer Inc., Shelton, CT 06484, USA) (Golubkina et al., 2017).

Data were processed by analysis of variance and means separations were performed with the Duncan multiple range test, with reference to the 0.05 probability level, using SPSS software version 21. Data expressed as percentages were subjected to angular transformation before processing. The factor "year of research" had no significant effects on the variables examined, both in terms of main effects and of interactions with the factor "cultivar". Therefore, we have reported the meaningful results obtained by data statistical processing as means of the two years of research.

RESULTS AND DISCUSSION

Yield, quality indicators and antioxidants

As shown in Table 1, the *P. angulata* cultivars 'Konditer' and 'Konditer 2' gave the highest yield (11.3 and 11.0 t ha^{-1}, respectively) due to the highest mean berry weight (70 and 80 g, respectively), whereas the *P. pubescens* variety 'Zolotaya Rossip' had the worst outcome in spite of the huge number of fruits per plant, which were, however, very small (3 g). Among the *P. angulatum* varieties, 'Lakomka' and 'Lezhky' showed the lowest yields (7.3 and 7.7 t ha^{-1}, respectively) due to the lowest prolificacy and the smallest fruits, respectively. From the above, it may be inferred that in the *P. pubescens* and *P. angulatum* cultivars, the significant variations in fruit yield were mainly due to the mean weight of berries or their number per plant, depending on the variety. In this respect, the priority in the selection of *P. angulatum* genotypes in Russia has been fruit weight and low temperature resistance, which has resulted in wide differences between Russian and foreign cultivars in respect of both features. In fact, *P. angulatum* varieties grown in Brazil (De Souza et al., 2017) showed mean fruit weight of 12 to 14 g, that is 4.5 to 6.5 times lower than those recorded for Russian cultivars, those in our research (Tab. 1) and in other investigations (Mamedov and Engalychev, 2017). Russian *P. angulatum* varieties are also characterized by twice the number of seeds per fruit (Mamedov and Engalychev, 2017) compared with berries produced by Brazilian *P. angulata* genotypes (De Souza et al., 2017), which may even affect fruit growth. Further, genotype selection for plant resistance to abiotic and biotic stresses, i.e. low temperature and parasite attack, respectively, has been a major goal in *P. angulata* and *P. pubescens*, enabling successful cultivation in Russia (Mamedov et al., 2017), similarly to what has been done in other vegetable species in northern Europe (Stoleru et al., 2012).

As for quality indicators, *P. pubescens* fruits attained higher values of dry residue and soluble solids compared to all *P. angulata* cultivars; among the latter, 'Violet' showed the highest levels of these quality indicators. In our research, dry matter and soluble solids in *P. pubescens* are similar to those detected in *Physalis* berries grown in tropical and subtropical countries (Yıldız et al., 2015); soluble solids highly represent the reducing sugars content, which reportedly affects fruit quality and flavour (Doras et al., 2001), and, according to reports by Olivares-Tenorio et al. (2016), the main

Table 1. Yield, quality and antioxidant content of *P. angulata* and *P. pubescens* cultivars

Cultivar	Fruits per plant (no.)	Yield (t ha^{-1})	Mean fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Dry matter (%)	Soluble solids (°Brix)	Polyphenols (mg GAE g^{-1} d.w.)	Ascorbic acid (mg kg^{-1} d.w.)
Violet	58 cd*	9.0 b	60 c	4.5 d	5.1 de	10.5 b	8.1 b	25.1 a	0.96 c
Korolek	64 b	9.3 b	56 cd	4.1 d	4.9 e	9.3 d	5.9 c	18.7 d	1.33 a
Lakomka	47 f	7.3 c	60 c	5.2 c	5.8 bc	8.5 e	6.0 c	22.6 b	1.31 ab
Konditer	62 bc	11.3 a	70 b	5.1 c	5.5 cd	10.0 bc	5.9 c	20.4 c	1.26 ab
Konditer 2	53 e	11.0 a	80 a	6.8 a	9.0 a	9.7 cd	5.9 c	19.5 cd	1.27 ab
Lezhky	55 de	7.7 c	54 d	6.0 b	6.1 b	8.7 e	4.9 d	19.8 cd	1.24 b
Zolotaya Rossip	165 a	1.3 d	3 e	1.0 e	0.8 f	15.5 a	9.7 a	20.5 c	0.64 d

*Within each column, means followed by different letters are significantly different according to the Duncan multiple range test at $p \leq 0.05$

carbohydrates of *Physalis* fruits are sucrose and glucose.

In the present research, the cultivation of *P. pubescens* and *P. angulata* cultivars in the same geochemical environment (central Russia) resulted in fruit polyphenol accumulation ranging from 18.7 to 25.1 mg GAE 100 g^{-1} d.w. (Tab. 1). Notably, the top concentration detected in 'Violet' was 34.2% higher than the lowest level recorded in 'Korolek', whereas *P. pubescens* 'Zolotaya Rossip' ranked third. In previous research (Medina-Medrano et al., 2015), higher phenolic values had been detected in the fruits of five *Physalis* wild species grown in Mexico (32 to 86 mg GAE g^{-1} d.w.), with the lowest concentrations recorded in *P. angulata* berries. Moreover, *P. peruviana* fruits accumulated 400 to 600 mg GAE 100 g^{-1} f.w. in Colombia (Narvaez-Cuenca et al., 2014), but this species is not suitable for a northern European environment (Kondratieva and Engalichev, 2013). Among the natural secondary plant metabolites, polyphenols are considered the strongest antioxidants, able to inhibit carcinogenesis at all stages, thus suggesting the great importance of their accumulation in agricultural plants (Yang et al., 2001).

The correlations between polyphenols and dry matter content were positive and highly significant (r = 0.91 at $p \leq 0.001$). The high statistical significance of the correlations between the above parameters highlights the quality performance of 'Violet', which showed the highest concentrations of polyphenols and dry matter content among the *P. angulata* varieties and of *P. pubescens* 'Zolotaya rossip' with an even higher dry matter content than 'Violet'. These features may be exploited in *Physalis* breeding for increasing fruit nutritional quality.

In our research, vitamin C concentration in *P. angulata* cultivars ranged from 0.96 mg g^{-1} d.w. ('Violet') to 1.33 mg g^{-1} d.w. ('Korolek'); however, the lowest value was recorded in the berries of *P. pubescens* cv. 'Zolotaya Rossip' (Tab. 1). These results show that the synthesis of this antioxidant in Russia is much lower than that reported for *P. peruviana* and *P. pubescens* in tropical and subtropical areas: i.e. 10 to 30 vs 20 to 50 mg 100 g^{-1} f.w. (El Sheikha et al., 2010; Olivares-Tenorio et al., 2016). Indeed, the higher light intensity occurring at lower latitudes enhances ascorbic acid accumulation (Bartoli et al., 2006), whereas in previous investigations carried out in Colombia, Kenia and Southern Africa (Fischer et al., 2000) no relationship of this antioxidant with altitude was found. Moreover, the low vitamin C variability obtained in the present investigation proves the predominance of environmental effects over the genetic one in affecting antioxidant accumulation in *Physalis* fruits (Tab. 1). Notably, the outer husk of *Physalis* fruits is known to prevent ascorbic acid oxidation (Valdenegro et al., 2012) and, despite the relatively low vitamin C content, 100 g of fresh *Physalis* fruits produced in the northern hemisphere can supply the human organism with 14 to 21% of the required vitamin C consumption (70 mg per day).

As for organic acids, in our research, tartaric, malic and citric acids exceeded 90% of the total acid content recorded in the *P. angulata* and *P. pubescens* cultivars, except for 'Konditer 2', which showed only 73.8% (Tab. 2). Notably, tartaric acid was the most representative in most cultivars; in fact, it was just lower than malic acid in 'Korolek' and than malic and citric in 'Lezhky'. Moreover, 'Konditer 2' showed the highest total concentration of organic acids, 'Violet' the highest tartaric acid content, 'Zolotaya Rossip' (*P. pubescens*) the highest concentration of malic and oxalic acids, 'Lakomka' the highest amount of citric acid, and 'Lezhky' the lowest concentration of all the organic acids detected, except for malic being the lowest in 'Korolek'. Consistent with our findings, Fischer et

Table 2. Composition of organic acids in *P. angulata* and *P. pubescens* fruits (mg kg^{-1} d.w.)

Cultivar	Tartaric	Malic	Citric	Oxalic	Succinic	Maleic	Total
Violet	89.9 a*	36.6 c	7.2 e	0.41 c	1.8 d	0.000 d	135.9 b
Korolek	9.8 e	36.2 c	9.6 d	0.73 b	1.7 d	0.001 d	58.0 e
Lakomka	41.7 d	14.5 f	21.7 a	0.05 d	0.0 e	0.000 d	77.9 d
Konditer	72.5 b	22.5 e	15.5 b	0.35 c	5.2 c	0.004 c	116.1 c
Konditer 2	56.7 c	47.1 b	10.0 d	0.14 d	40.0 a	0.043 a	153.9 a
Lezhky	0.7 f	27.5 d	6.9 e	0.09 d	0.2 e	0.001 d	35.4 f
Zolotaya Rossip	55.7 c	52.5 a	12.1 c	1.96 a	9.4 b	0.009 b	131.7 b

*Within each column, means followed by different letters are significantly different according to the Duncan multiple range test at $p \leq 0.05$

al. (2000) had reported that citric, malic and tartaric acids were the main organic acids in *Physalis* fruits, but, unlike our results, citric acid was the most representative. However, the concentration of organic acids recorded in *Physalis* fruits grown in northern Europe conditions in our research is lower than the one reported in *P. peruviana* (Fischer et al., 2000), both in *P. pubescens* and even more so in *P. angulata*. This phenomenon may be connected either with the species peculiarity or with environmental influence, but the lack of investigation on the organic acid profile of these *Physalis* species to date does not allow us to benefit from any related reports.

From our findings, it may be inferred that the acid profile of *Physalis* fruit is highly specific and also charactarizes the cultivar's fruit quality, as organic acids contribute to the sensory properties, i.e. taste and aroma.

Elemental composition

The analysis of concentrations of twenty-five elements performed in our research (Tabs 3-5) showed mineral composition similarity between *P. pubescens* and *P. angulata* fruits grown in the same environmental conditions. An exception is represented by Li (Tab. 4), whose high concentration in *P. pubescens* 'Zolotaya Rossip' fruits suggests its possible medicinal value in neurological diseases prophylaxis (Lazzara and Kim, 2015). Moreover, the occurrence of B, Co, Li, Si and V in *Physalis* fruits, revealed for the first time in our research, suggests additional benefits connected with the consumption of this fruit. Interestingly, the high V concentration may protect the organism against anaemia, diabetes, cancer, heart disease, high blood pressure and obesity (Mukherjee et al., 2004), while high Co ingestion may also improve hematopoiesis.

As for varietal differences in berry element accumulation, the lowest variability in *P. angulata* fruits was shown by P, Mg, B, Fe, Mn and Zn (8.5 to 11.6%); the widest varietal differences were recorded for Li, I, Na and heavy metals such as Cd, Ni, Sn and Pb (32.4 to 47.9%). A positive correlation was recorded between Fe and Mn concentrations in our research (r = 0.97; $p < 0.001$), which is in agreement with the reports relevant to other plants species (Kabata-Pendias, 2011). Moreover, the negative correlation detected between Si and Cd (r = -0.94; $p < 0.001$) is consistent with the previous

Table 3. Composition of macroelements in *P. angulata* and *P. pubescens* fruits

Cultivar	Ca	K	Mg	Na	P	NO_3^-
	(mg kg^{-1} d.w.)					
Violet	415 b*	2465 ab	1449 c	51 b	3483 c	2390 a
Korolek	722 a	2013 d	1740 ab	48 b	3825 b	2108 b
Lakomka	763 a	1284 f	1845 a	53 b	4345 a	2365 a
Konditer	720 a	2300 bc	1809 a	34 b	4277 a	1990 bc
Konditer 2	739 a	1723 e	1614 b	6 c	3503 c	1876 c
Lezhky	797 a	2152 cd	1286 d	61 b	3509 c	2287 a
Zolotaya Rossip	414 b	2561 a	1708 ab	293 a	3572 c	1181 d

*Within each column, means followed by different letters are significantly different according to the Duncan multiple range test at $p \leq 0.05$

Table 4. Composition of microelements in *P. angulata* and *P. pubescens* fruits

Cultivar	B	Co	Cu	Fe	I	Li	Mn	Se	Si	Zn
	(mg kg^{-1} d.w.)									
Violet	5.5 e*	0.05 c	8.5 a	64.9 ab	0.10 b	0.04 d	13.4 c	0.03 bc	11.6 a	20.7 a
Korolek	7.6 a	0.04 c	7.2 a	70.5 a	0.10 b	0.05 d	13.7 c	0.04 ab	9.3 a	15.3 b
Lakomka	6.9 bc	0.05 c	4.6 b	70.1 a	0.12 a	0.18 a	14.0 c	0.05 a	6.7 b	22.2 a
Konditer	7.4 ab	0.05 c	8.5 a	78.4 a	0.05 d	0.05 d	16.8 a	0.03 bc	6.5 b	14.7 b
Konditer 2	7.9 a	0.07 b	8.2 a	78.1 a	0.05 d	0.04 d	15.5 b	0.05 a	9.0 a	22.6 a
Lezhky	6.2 d	0.10 a	5.6 b	58.6 b	0.05 d	0.08 c	10.2 d	0.02 c	10.0 a	16.6 b
Zolotaya Rossip	6.4 cd	0.04 c	5.3 b	52.2 b	0.08 c	0.13 b	10.1 d	0.02 c	6.4 b	21.2 a

*Within each column, means followed by different letters are significantly different according to the Duncan multiple range test at $p \leq 0.05$

Table 5. Compostion of heavy metals in *P. angulata* and *P. pubescens* fruits

Cultivar	Cd	Cr	Ni	Pb	Sn	Sr	V
	(mg kg^{-1} d.w.)						
Violet	0.05 d*	0.17 ab	0.15 d	0.35 b	0.21 b	3.2 c	0.18 a
Korolek	0.10 c	0.20 a	0.37 b	0.19 cd	0.24 b	3.2 c	0.16 ab
Lakomka	0.17 b	0.14 bc	0.27 c	0.28 bc	0.12 c	4.8 b	0.12 bc
Konditer	0.23 a	0.11 c	0.37 b	0.15 d	0.36 a	4.2 b	0.09 cd
Konditer 2	0.12 c	0.17 ab	0.66 a	0.21 cd	0.19 b	9.1 a	0.07 d
Lezhky	0.12 c	0.21 a	0.57 a	0.44 a	0.05 d	4.5 b	0.10 cd
Zolotaya Rossip	0.21 a	0.14 bc	0.26 c	0.21 cd	0.10 cd	5.1 b	0.14 ab

*Within each column, means followed by different letters are significantly different according to the Duncan multiple range test at $p \leq 0.05$

findings concerning the protection effect of silicon against cadmium stress in strawberry plants (Treder and Cieslinski, 2005). In this respect, an interesting feature of *P. angulata* 'Violet' is the concurrent low Cd concentration and high Si. Indeed, Si is reportedly beneficial both for plant growth (Sahebi et al., 2015) and human health (Prashanth et al., 2015) and, in addition, inside the plant this element minimizes the toxicity of Fe, Al, and Mn, increases the availability of P, and enhances drought as well as salt tolerance.

As shown in Table 5, significant interspecies and varietal variations in fruit heavy metal concentration arose between the cultivars examined. In this respect, *P. angulata* 'Lezhky' showed the highest berry total concentration of heavy metals and 'Konditer' the lowest. Notably, each *Physalis* cultivar showed very low ability in accumulating some heavy metals: 'Violet' for Cd, Ni, Sr; 'Korolek' for Sr; 'Konditer' for Pb; 'Konditer 2' for Al and V; 'Lezhky' for Sn. Moreover, the fruits of five out of the six *P. angulata* varieties accumulated more Sn and Ni, but less Cd, compared to the *P. pubescens* cultivar.

The few literature reports concerning the important topic of edible plant elemental composition for the human organism do not allow performing proper interspecific or varietal comparisons with the results of our investigation due to quite different geographic and environmental conditions; indeed, previous research had been carried out in tropical areas on *P. peruviana* (Leterme et al., 2006; Rodrigues et al., 2009), or in Egypt on *P. pubescens* (El-Sheikha et al., 2010). However, based on the concentrations of the elements detected in our research and reference to RDA values (DRI, 2001), upon consumption of 300 g fresh *Physalis* fruits per day, the nutritional requirements are best fulfilled in respect of K (24.8%), Cu (21.3%), Fe (20.3%), Mn (21%), Co (18.3%), V (18.2%), P (14.4%), Mg (12.3%) and B (10.5%); Si, Zn and Li percentages are less significant (5.4, 4.8 and 2.2%, respectively). All these elements are beneficial or even essential to human health, and their adequate consumption guarantees high immunity, optimization of the metabolism of carbohydrates, proteins and lipids, and protection against cancer. They improve bone strength and brain activity, protect against cardiovascular diseases, obesity and diabetes. Accordingly, *P. angulata* and *P. pubescens* fruits may be considered good sources of several mineral nutrients, as also previously reported for *P. peruviana* berries (Zhang et al., 2013).

CONCLUSIONS

The present research, carried out in central Russia, made it possible to assess interspecies and varietal differences in the production, quality, antioxidant and mineral element features of *P. angulata* and *P. pubescens* fruits grown under organic management. In this respect, this investigation provided interesting clues, mainly concerning the nutritional and antioxidant properties of the cultivars tested and their prospects for cultivation by organic farming procedures in northern Europe. The variability of biologically active compounds, macro- and microelement content, as well as the significant correlations between them may serve as a basis for enhancing the high potential of *Physalis* varieties for functional food production.

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AUTHOR CONTRIBUTIONS

N.G. – designed the experiments and performed analytical measurements; H.K. – performed analyses of organic acids; M.E. – produced *Physalis* fruit; M.A. – participated in obtaining elemental composition data; G.C. and N.G. – equally contributed to manuscript writing and performance of statistical analysis.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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