

# Yield, quality, antioxidants and mineral nutrients of *Physalis angulata* L. and *Physalis pubescens* L. fruits as affected by genotype under organic management

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All relevant data are within the paper and its Supporting Information files.

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**Abstract:** Introduction and selection of unconventional plants with high concentration of biologically active compounds is one of the worthy ways for producing functional food, which is beneficial to human health. Research was carried out in northern Europe (Russia) with the purpose to assess yield, quality and biologically active compounds concentration in *Physalis angulata* and *Physalis pubescens* fruits. *P. angulata* cultivars Konditer and Konditer 2 gave the highest yield (11.3 and 11.0 t·ha<sup>-1</sup> respectively), due to the highest mean fruit weight (80 and 70 g respectively); *P. pubescens* variety Zolotaya rossip had the worst outcome due to the very small berries (3 g), in spite of their highest number per plant (165). 'Zolotaya rossip' fruits overall attained higher values of quality indicators compared to all *P. angulata* cultivars. Positive correlations were recorded between dry matter and polyphenols as well as between total sugars and polyphenols. *Physalis* fruits showed to be a good source of antioxidants, K, Mg and P for human beings. Taste index turned out highly reliable in evaluating fruit quality and it was dependant on dry matter, total sugars, polyphenols and Ca.

## 1. Introduction

The availability of new functional food has been becoming more and more important for human health regulation and protection against the major diseases of the millennium.

*Physalis* fruit is mostly an exotic product, imported from tropical and subtropical regions, particularly from Central America, where this genus is characterized by the highest biodiversity (Medina-Medrano *et al.*, 2015). The popularity of this genus plants has been increasing in several world

Countries, due not only to its high nutritional value and exclusive taste (Puente *et al.*, 2011), but also to its effectiveness as a medical plant. Indeed, all plant parts are useful in modern medicine for their properties: antiasthma, antihepatitis, antimalaria and anti-dermatitis (Chang *et al.*, 2008), antiallergenic, anti-carcinogenic, anti-inflammatory, antihyperglycemic, antimicrobial, antiseptic, antiviral, cardio-protective, diuretic, expectorant, febrifuge (Bastos *et al.*, 2006; Sharma *et al.*, 2015). In this respect, a negative correlation has been shown between the level of *Physalis* consumption and the risk of cardiovascular, pulmonary and gastrointestinal diseases (Leenders *et al.*, 2014; Hjartaker *et al.*, 2015). Moreover, the high antioxidant activity of water and alcoholic extracts of *Physalis* is reportedly beneficial to patients suffering from Alzheimer's disease as well as from memory and concentration deficit (Susanti *et al.*, 2015). Among the tens of *Physalis* species, *P. angulata* and *P. pubescens* are the most suitable for production in the northern Europe, due to their frost resistance and tolerance to fungal and bacterial diseases (Mamedov *et al.*, 2017). Notably, the genetic selection carried out in Russia allowed to create interesting varieties, suitable for cultivation both in central Russia (Kondratieva and Engalichev, 2013; Mamedov *et al.*, 2017) and in Siberia (Makarov, 2002), mainly belonging to *P. angulata*. However, a few results concerning the variability of interspecies quality characteristics and even no cultivar comparisons of biologically active compounds accumulation in *Physalis* fruits have been published so far.

Taking into account the scarcity of literature reports, the present research was aimed at evaluating the varietal differences in yield, quality and antioxidant content of *P. angulata* and *P. pubescens* fruits grown in northern Europe.

## 2. Materials and Methods

### Growth conditions

Six *P. angulata* L. cultivars (Violet, Lakomka, Konditer, Konditer 2, Lezhky, Korolek) and one *P. pubescens* L. cultivar (Zolotaya rossip) were compared in a research carried out, under the 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 trial was conducted on a clay-loam soil, with pH 6.8, 2.1% organic matter, 108 mg·kg<sup>-1</sup> N,

450 mg·kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, 357 mg·kg<sup>-1</sup> K<sub>2</sub>O, exchangeable bases sum as much as 95.2%. The air temperature values, recorded at plant level, were: 14.2°C and 13.5°C in May, 16.9°C and 17.1°C in June, 21.2°C and 20.4°C in July, 19.3°C and 18.0°C in August, 12.1°C and 12.2°C in September, in 2015 and 2016 respectively.

A randomized complete blocks design, with three replicates, was used for treatments distribution in the field; each treatment had a 19.25 m<sup>2</sup> (5.5 × 3.5 m) surface area, including 50 plants.

*Physalis* seeds were sown in peat boxes on 14 April and the seedlings were transplanted in the field on 23 May, spaced 55 cm along the rows, the latter being 70 cm apart. As for *P. angulata*, the six cultivars chosen for the trial are the most spread in Russia, whereas within *P. pubescens* only the cultivar Zolotaya rossip tested in our research is cultivated in this Country.

The organic farming practice complied with EC Regulation 834/2007. *Physalis* crops were preceded by pea and each year the fertilization supplied the crops with 56 kg ha<sup>-1</sup> of N, 16 of P<sub>2</sub>O<sub>5</sub> and 98 of K<sub>2</sub>O. Half of the fertilizers dose was given just before transplanting and the remaining 50% on dressing at two week intervals. Drip irrigation was practiced for watering the crops when needed. Plant protection from fungal diseases and insects was achieved by adopting Trichoderma suspensions, copper, sulphur, azadirachtin.

Harvests were carried out from mid-August to the end of September.

### General analytical methods

Ripe, undamaged and regularly shaped fruits were classified as "marketable". At each harvest, the weight and number of marketable fruits in each plot was recorded and the mean weight was assessed on random samples of 50 fruits per 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.

### Samples preparation

Prior to analyses, *Physalis* fruits were extracted from papery husk and homogenized with a stainless steel blender for 1 min. The resulting homogenates

were immediately subjected to the analysis.

#### Total soluble solids (TSS) and sugars

Determination of total soluble solids was carried out by a refractometer (IRF-22, Russia). The results were reported as °Brix at 20°C.

Mono- and disaccharides were determined using cyanide method (Kidin, 2008).

#### Titrateable acidity (TA)

TA was measured using 20 ml of the water *Physalis* extract (1:1), titrated to pH 8.1 using 0.1 N NaOH (GOST, 1996). The following formula was used for calculation:

$$TA = V_1 \times 0.1 \times 0.064 \times 100 : 20$$

where  $V_1$  is the volume of NaOH used; 0.1 is the NaOH normality; 0.064 is the weight of a citric acid milliequivalent in g; 20 is the volume of the *Physalis* extract used.

#### Mineral nutrients

K, Mg, Mn, Ca, Na and P contents in dried homogenized fruit samples were assessed using ICP-MS on quadruple mass-spectrometer Nexon 300D (Golubkina et al., 2017). Nitrate content in fresh fruits of *Physalis* species was determined using ion-selective electrode on ionomer Expert-001 (Russia), as previously described (Golubkina et al., 2017).

#### Antioxidants

Total polyphenols were assessed using Folin-Ciocalteu colorimetric method (Sagdic et al., 2011). The ascorbic acid content was determined by visual titration of fruit extracts in 6% trichloroacetic acid with Tillmans reagent (AOAC, 2012).

#### Taste

The assessment of *Physalis* taste was performed using two methods: chemical and organoleptic. Taste

index was calculated starting from the Brix degree and acidity values, using the equation proposed by Navez et al. (1999) and Nielsen (2003) for tomato fruits:

$$TI = (\text{Brix}/20 \text{ TA}) + \text{TA}$$

where TI is the taste index and TA is the titrateable acidity calculated referring to citric acid.

Though organoleptic perception of taste depends on the cultural background of judges and cannot be considered universally objective, *Physalis* fruit taste was evaluated additionally by 10 experts, via sensory analysis using 5 balls scales (Krueger and Casey, 2000).

#### 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. Data expressed as percentage were subjected to angular transformation before processing. Notably, the factor “year of research” had no significant effects on the variables examined, both in terms of main effects and of interactions with the other experimental factor. Therefore, we have reported the results obtained from the data statistical processing as means of the two years of research.

### 3. Results and Discussion

#### Plant growth and yield

As it can be seen in Table 1, a correspondence between plant height and dry matter was recorded in *P. pubescens* variety Zolotaya rossip, which had the smallest plants and the lowest dry matter, whereas within *P. angulata* the cultivar Korolek showed the

Table 1 - Biometrical, growth and yield parameters of *P. angulata* and *P. pubescens* cultivars

Cultivar	Plant height (cm)	Plant dry weight (g·m <sup>-2</sup> )	Planting to harvest beginning (days)	Fruits per plant (no.)	Yield (t·ha <sup>-1</sup> )	Mean fruit weight (g)
Violet ( <i>P. angulata</i> )	90 d	296.6 c	105 bc	58 cd	9.0 b	60 c
Korolek ( <i>P. angulata</i> )	130 a	320.3 c	108 b	64 b	9.3 b	56 cd
Lakomka ( <i>P. angulata</i> )	105 c	200.7 d	90 d	47 f	7.3 c	60 c
Konditer ( <i>P. angulata</i> )	125 ab	402.5 a	115 a	62 bc	11.3 a	70 b
Konditer 2 ( <i>P. angulata</i> )	120 b	368.3 b	102 c	53 e	11.0 a	80 a
Lezhky ( <i>P. angulata</i> )	110 c	223.6 d	118 a	55 de	7.7 c	54 d
Zolotaya rossip ( <i>P. pubescens</i> )	80 e	133.3 e	85 e	165 a	1.3 d	3 e

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

tallest plants but ‘Konditer’ and ‘Konditer 2’ produced the highest dry matter amounts. The latter cultivar was characterized by the longest crop cycle, similarly to Lezhky, and *P. pubescens* Zolotaya rossip resulted in the earliest fruit ripening; among *P. angulatum* varieties, only ‘Lakomka’ showed early ripeness comparable to ‘Zolotaya rossip’ one. Correspondently to plant dry matter production, *P. angulata* cultivars Konditer and Konditer 2 also gave the highest yield (11.3 and 11.0 t·ha<sup>-1</sup> respectively), due to the highest mean berry weight (80 and 70 g respectively), whereas *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 *P. angulatum* varieties, Lakomka and Lezhky showed the lowest values (7.3 and 7.7 t·ha<sup>-1</sup> respectively), due to the lowest prolificity and the smallest fruits respectively.

**Quality indicators and mineral nutrient content**

As reported in Table 2, the fruits of *P. pubescens* cultivar Zolotaya rossip overall attained higher values of quality indicators than the six *P. angulata* varieties examined; compared to the average of the latter six cultivars, *P. pubescens* fruits showed 1.6 and 1.95 times higher content of total sugars and monosaccharides respectively as well as 1.27 times higher

titratable acidity. Among *P. angulata* cultivars, in ‘Violet’ fruits the highest levels of dry residue, soluble solids and total sugars were recorded and in ‘Lezhky’ the lowest. Otherwise, ‘Lakomka’ showed the highest monosaccharide content (32.2% out of total sugars) and cultivar Violet the lowest (18.8%); the variation coefficient relevant to monosaccharide content in *P. angulata* species attained 18.3%. As for quality indicators, the *Physalis* cultivars tested showed high variability in the content of dry matter (15.0%) and sugars (28.2%) as well as in juice acidity (16.7%), whereas the juice pH variability was low (2.1%).

In our research, dry matter and sugar content in *P. pubescens* are similar to those detected in *Physalis* berries grown in tropical and subtropical countries (Yildiz *et al.*, 2015). Notably, soluble sugars highly affect flavour quality of tomato fruits (Doras *et al.*, 2001) and, according to Olivares-Tenorio *et al.* (2016) reports, the main carbohydrates of *Physalis* fruits are sucrose and glucose, whereas fructose content is neglectable.

The analysis of mineral nutrient content performed in our research showed the close element concentrations of *P. pubescens* and *P. angulata* fruits grown in the same environmental conditions (Table 3). As for varietal differences in mineral nutrient

Table 2 - Quality indicators of *Physalis angulata* and *P. pubescens* cultivars fruits

Cultivar	Dry matter (%)	Soluble solids (°Brix)	Total sugars (%)	Reducing sugars (%)	Titrateable acidity (%)	pH
Violet	10.5 b	8.1 b	7.8 b	1.8 d	0.79 c	4.82 ab
Korolek	9.3 d	5.9 c	5.6 d	1.8 d	0.70 d	4.65 bc
Lakomka	8.7 e	6.1 c	6.0 c	2.9 b	0.45 f	4.94 a
Konditer	10.0 bc	6.0 c	5.9 cd	1.6 d	0.88 b	4.62 bc
Konditer 2	9.7 cd	6.1 d	5.9 c	2.2 c	0.79 c	4.51 c
Lezhky	8.5 e	4.9 d	4.7 e	1.7 d	0.63 e	4.70 ac
Zolotaya rossip	15.5 a	9.7 a	9.6 a	3.9 a	0.90 a	4.72 ac
Mean	9.5	6.2	6.0	2.0	0.71	4.71

Within each column, means followed by different letters are significantly different according to the Duncan multiple range test at p≤0.05.

Table 3 - Mineral nutrient concentrations in *Physalis angulata* and *P. pubescens* cultivars fruits (mg kg<sup>-1</sup> d.w.)

Cultivar	Ca	K	Mg	Na	P	NO <sub>3</sub> <sup>-</sup>
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≤0.05.

accumulation, in *P. angulata* fruits the variability was high in Na concentration (33%) and low in Mg, P and nitrates (11.6, 8.5 and 6.9%).

Recently, the element composition of vegetable edible parts has been drawing attention as one of the most important factors affecting human being ingestion of mineral nutrients. Unfortunately, the few literature reports available do not give the opportunity to perform correct interspecific or varietal comparisons, due to research carried out under different environmental conditions and species (El-Sheikha et al., 2010; Eken et al., 2014).

Referring to recommended dietary allowance values (Institute of Medicine, 2001), the consumption of 300 g fresh *Physalis* fruits per day results in the ingestion of 24.8% potassium, 14.4% phosphorous and 12.3% magnesium needed by human organism. The latter benefits from these mineral nutrients in terms of optimization of carbohydrates, protein and lipid metabolism, bone integrity and brain activity, protection against cancer as well as cardiovascular diseases, obesity and diabetes. In this respect, *P. angulata* and *P. pubescens* fruits as well as the *P. peruviana* ones (Zhang et al., 2013) may be considered as good sources of several elements.

#### Antioxidants

**Polyphenols.** In the present research, *P. pubescens* and *P. angulata* cultivars growing in the same geochemical environment (central Russia) resulted in fruit polyphenols accumulation ranging between 18.7 and 25.1 mg GAE/g d.w. (Fig. 1). Notably, the top concentration detected in the cultivar Violet was 34.2% higher than the lowest level recorded in 'Korolek', both belonging to *P. angulata* species; *P. pubescens* cultivar Zolotaya rossip ranked third (20.5 mg GAE/g d.w.). Compared to our findings, in previous research (Medina-Medrano et al., 2015) higher phenolic values were detected in the fruits of five *Physalis* wild species grown in Mexico (32 to 86 mg AGE/g d.w.), with the lowest concentrations recorded in *P. angulata* berries. Moreover, *P. peruviana* fruits produced in Colombia accumulated 400 to 600 mg GAE/g f.w. of polyphenols (Narvaez-Cuenca et al., 2014), but unfortunately this species is not suitable for cultivation in northern Europe (Kondratieva and Engalichev, 2013). Indeed, among natural secondary plant metabolites, polyphenols are considered to be the strongest antioxidants, which are able to inhibit carcinogenesis at initial and development stages, thus suggesting the great importance of their accumulation in agricultural plants (Yang et al., 2001).

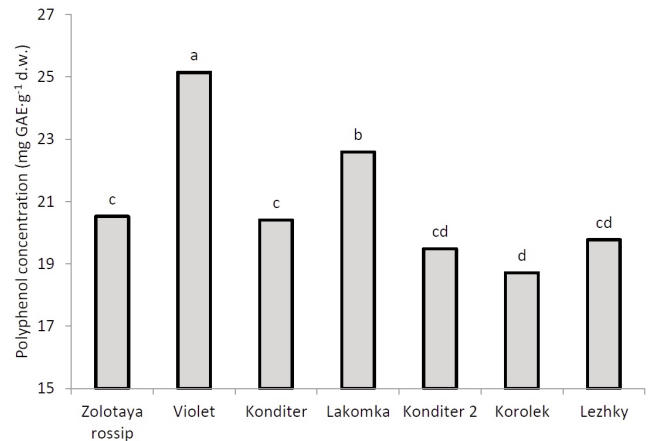


Fig. 1 - Polyphenol concentration as a function of *Physalis* cultivar. Means followed by different letters are significantly different according to the Duncan multiple range test at  $p \leq 0.05$ .

The correlations between polyphenols and total sugars concentrations and between polyphenols and dry matter content were positive and highly significant ( $r = 0.99$  and  $r = 0.91$ , respectively, at  $P \leq 0.001$ ). The first one is supposed to reflect the existence of phenolic glycosides, identified as the main phenolics in wild *Physalis* species (Medina-Medrano et al., 2015). The second correlation explains the higher dry matter and phenolics contents detected in *Physalis* fruits produced in southern Countries compared to those obtained in central Russia. The high statistical significance of the correlations between the above parameters gives the opportunity to highlight the quality performances of cultivar Violet, which showed the highest concentrations of polyphenols as well as the highest carbohydrates and dry matter content among *P. angulata* varieties and *P. pubescens* cultivar Zolotaya rossip, with the highest content of dry matter and carbohydrates. These parameters may be used in *Physalis* breeding for increasing fruit nutritional quality.

**Ascorbic acid.** In our research, vitamin C concentration in *P. angulata* cultivars ranged from 0.96 mg/g d.w. (cultivar Violet) to 1.33 mg/g d.w. (cultivar Korolek); however, the lowest value was recorded in the berries of *P. pubescens* cultivar Zolotaya rossip (Fig. 2). 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 f.w. (El Sheikha et al., 2008, 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 investi-

gations carried out in Colombia, Kenya and Southern Africa (Fischer *et al.*, 2000), no relationship of this antioxidant with the altitude was found. Moreover, the low vitamin C variability obtained in the present investigation prove the predominance of environmental effects on the genetic one in affecting this antioxidant accumulation in *Physalis* fruits (Fig. 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 human organism with 14 to 21% of the required vitamin C consumption (70 mg per day).

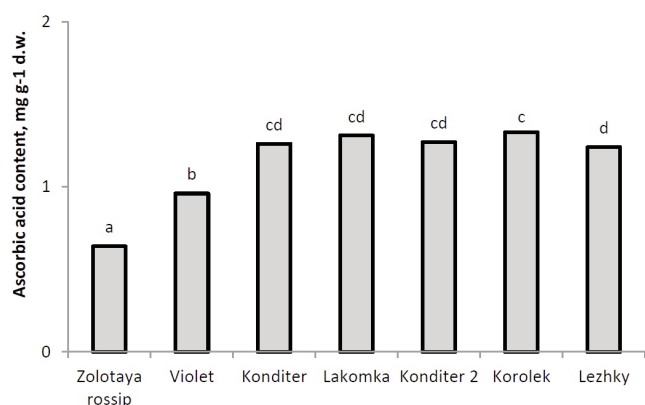


Fig. 2 - Ascorbic acid concentration as a function of *Physalis* cultivar. Means followed by different letters are significantly different according to the Duncan multiple range test at  $p \leq 0.05$ .

### Taste

Among *P. angulata* and *pubescens* cultivars examined, the highest taste index (TI) and nutritional values were recorded in 'Zolotaya rossip' (*P. pubescens*) and 'Violet' (*P. angulata*). As far as taste assessment is concerned, it is a critical point in nonconventional plants produce and, indeed, this determination has never been performed on *Physalis* fruits up to date. A general approach based on tomato berry testing suggests several significant factors affecting taste: dry matter, soluble solids, juice electrical conductivity, carbohydrates and organic acids contents (Adams and Ho, 1989; Clement *et al.*, 2008). In our research, we have assessed that the taste index (TI) used for tomato fruits can be successfully used for *Physalis* berries. Indeed, the organoleptic analysis and TI approach in evaluating *Physalis* fruit quality show a good convergence of the results and suggest signifi-

cant prospects of TI utilization in determining new varieties quality (Fig. 3).

In this respect, several correlations arose between the taste index and the following quality parameters of *Physalis* fruits: total sugar content ( $r = +0.98$ ;  $P < 0.001$ ), dry matter ( $r = +0.92$ ;  $P < 0.001$ ), polyphenol content ( $r = +0.96$ ;  $P < 0.001$ ); calcium ( $r = -0.91$ ;  $P < 0.001$ ). Notably, the two latter correlations had never been reported previously, neither in *Physalis* nor in tomato.

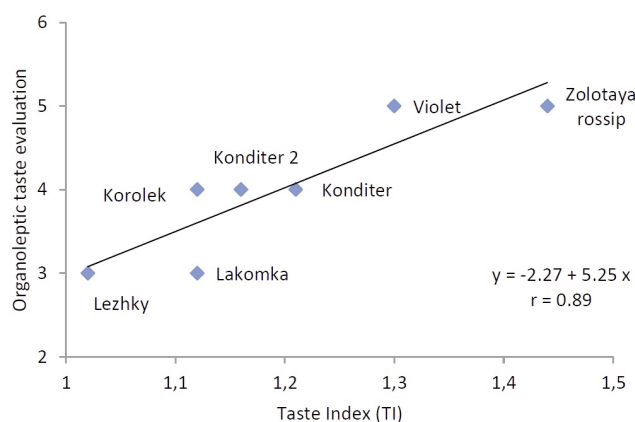


Fig. 3 - Correlation between taste index (TI) and organoleptic evaluation of *Physalis* taste.

### 4. Conclusions

The present research, carried out in central Russia, allowed to assess interspecies and varietal differences in yield and quality characteristics of *P. angulata* and *P. pubescens* fruits grown under organic management. In this respect, this investigation provided with interesting clues, mainly concerning the nutritional and antioxidant properties of the cultivars tested and their growing prospects by organic farming procedures in northern Europe. The variability of biologically active compounds, macroelement content and Taste Index, as well as their significant correlations may serve as the basis for enhancing the high potential of the *Physalis* varieties examined for functional food production.

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