J. Agr. Sci. Tech. (2019) Vol. 21(3): 683-697

Yield and Quality Traits of Field Grown Tomato as Affected by Cultivar and Nitrogen Application Rate

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ABSTRACT

This study was conducted in 2014-2015 to determine the effects of nitrogen (N) fertilization on yield, quality traits, and storage ability of two tomato cultivars, namely, 'Calista', for processing, and 'Volna', for fresh market. N was applied in doses of 0, 50, 100, and 200 kg N·ha^{-1}. Significant interactions were found between the studied years, N fertilization, and cultivars. Both tested cultivars produced high and similar yields in the year with good growing conditions during vegetation period. In the year with unfavorable weather conditions (lower average temperature, more total rainfall, and a smaller sum of GDD), cv. 'Volna' produced a significantly lower yield compared to the cv. 'Calista'. N fertilization had a significant impact on yield, however, the reaction of cultivars varied in each years. In 2014, quadratic positive regression was found between N rates and yield of cv. 'Calista' (R^2=0.90) and linear relation for cv. 'Volna' (R^2=0.77). In 2015, however a linear positive regression was found for cv. Volna (R^2=0.71) and cv. Calista (R^2= 0.44). The chemical and physical parameters of tomato quality varied depending on the year of cultivation. On average for the studied years and cultivar, increasing N fertilization affected the lycopene and soluble polyphenols content, as well as total flavonoids and ascorbic acid content and antiradical activity. N rate did not affect dry matter and soluble solids content, fruit firmness, fruit redness, and acidity. Cultivar 'Calista' had significantly higher lycopene content and better fruit firmness than cv. 'Volna' for fresh market. Furthermore, the storage ability of tomatoes cv. 'Calista' was significantly better than cv. 'Volna'.

Keywords: *Lycopersicon esculentum* L., N fertilization, Fruit storage, Tomato chemical composition, Fruits physical parameters

INTRODUCTION

Tomato plant is one of the most popular vegetable crops, widely grown and highly responsive to nitrogen fertilization. Nitrogen is one of the most important nutrients for plant growth; therefore, proper rate and time of application are very critical. Nitrogen rates that are recommended for growers depend on climatic conditions, method of cultivation, type of soil, and tomato cultivar. In experiments with tomatoes grown for single or multiple harvests, the N level of 100 kg ha^{-1} significantly increased marketable yield as compared to the control (0 kg N ha^{-1}), however, higher rates of N were effective in years with high precipitation (Kaniszewski and Rumpel, 1983). Iqbal *et al*. (2011) reported that under the local agro climatic conditions, tomato cultivar 'Rio Grand' produced maximum fruit size, early days to flowering and maturity, and economical yield per hectare when received 60 kg N ha^{-1} and 130 kg K ha^{-1}. Yield of direct seeded tomatoes increased significantly up to the rate of 225 kg N ha^{-1}on

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irrigated plots, whereas without irrigation yield increased up to the rate of 150 kg N ha^{-1} (Kaniszewski *et al.* 1987). Moreover, Warner *et al.* (2006) observed that responses of marketable yield to N rate were dependent on cultivar and year. When sufficient soil water was available, N rates of 200 kg N ha^{-1} or higher were required to produce the maximum marketable yield. In dryer years, the response to fertilizer N rate was cultivar dependent, and the application of 150 to 200 kg N ha^{-1} was sufficient to maximize marketable yield. Direkvandi *et al.* (2008) obtained highest yield of tomatoes by application of 225 kg N ha^{-1}. The study of Ortas (2013) clearly demonstrated that levels of N had a significant effect on the total yield of tomato plants and the highest yield was obtained if 200 kg N ha^{-1} was applied. Ozores-Hamton *et al.* (2012) reported that 172 and 298 kg N ha^{-1} produced maximum marketable yields in 2007 and 2008, respectively. During subsequent ripening, N rate did not correlate consistently to fruit ripening rate, fruit firmness, nor compositional quality at table-ripe stage. Warner *et al*. (2006) found that nitrogen rate did not affect the soluble solids content, firmness, and size or color of marketable fruits. Other studies showed that high N doses may have a significant negative effect on product quality as taste, vitamin C content, skin hardness and firmness (Kaniszewski *et al.* 1987). Also, it has been observed that low or too high N doses can have a detrimental effect on plant growth and quality of tomato fruits. Frias-Moreno *et al.* (2014) reported that tomato quality was affected by different N doses. The optimum N doses produced the highest yield and the highest fruit firmness, whereas high toxic N level significantly reduced fruit firmness by 25.0% and 31.9% for the cultivar 'Caballero' and 'Victoria', respectively. Soluble solids and titratable acidity increased with increasing N doses. Results obtained by Elkner *et al.* (2004) showed that tomato fertilization with N+K or complex fertilizers had a positive effect on ascorbic acid, lycopene, pectin, hemi-cellulose contents as compared to the control treatment without fertilization. The same results were obtained by Di Cesare *et al.* (2010) when N+P fertilizers were applied.

The conditions during growing season, including the fertilization, can affect the durability of tomatoes, which is extremely important during long distance shipment. Tomato is a highly perishable vegetable with limited postharvest life. The losses after harvest are still high and reach 20–50 % in developing countries (Abiso *et al.*, 2015; Etebu *et al.*, 2013; Mujtaba and Masud, 2014). Sainju *et al.* (2003) reported that N deficiency in the soil can decrease quality and the storage ability of the fruits. The same information is given in short communication of Di Cesare *et al.* (2010). However, according to Bartz *et al.* (1979), the increase of N fertilization increased susceptibility of tomatoes to disease, causing wet rot of the fruits. These studies also demonstrated that the method of N application and the raising of N/K ratio was associated with significant increase in fruit susceptibility to diseases development. Undesirable decrease in fruit firmness due to excessive N fertilization in several crops is mentioned by Sams (1999). The postharvest life of tomatoes usually does not exceed 2-3 weeks and is limited by physiological deterioration of the fruits and pathogen infection, which lead to fruit decay (Vinha *et al.*, 2013; Abiso *et al.*, 2015). According to Genanew (2013) the major determining factor of the post-harvest losses of tomato production is its seasonal nature. One of the important quality characteristics of horticultural products is their firmness related to fruit development as well as storage potential (Viskelis *et al.* 2008). Firmness declined during storage but this decrease is highly dependent on cultivar (De Ketelaere *et al*., 2004).

The aim of this study was to evaluate the effect of different N fertilizer rates on yield and quality of two cultivars of tomato grown in the field for fresh market and processing.

MATERIALS AND METHODS

The study was carried out on sandy loam soil with 1% organic matter and pH equal to 6.5 at the Research Institute of Horticulture (InHort, Skierniewice, Poland) using two cultivars of tomatoes (*Lycopersicon esculentum* L.), namely, cv. 'Volna' and 'Calista'. These cultivars are largely cultivated by producers for both fresh market ('Volna') and processing ('Calista'). Tomatoes were cultivated under different N fertilization rates (0, 50, 100, and 200 kg N$\cdot$ha^{-1}). Nitrogen fertilization in the form of ammonium nitrate was applied one week before planting. The highest N rate was supplied as the sum of two doses of 100 kg N ha^{-1}: the first was applied with all the other fertilizers as the pre-plant fertilization, whereas a second application of the same rate was supplied as side dress fertilization on June 23, about one month after transplanting to the field. The amounts of phosphorus and potassium were supplemented to the level required for tomatoes, which were 80 and 150 mg/L of soil, respectively. Transplants of tomatoes were produced in greenhouse. Seeds were sown on 11 and 10 of April in 2014 and 2015, respectively, to the multi-cell trays (Vefia 96 filled with prepared peat substrate "Select" from Klasmann-Deilman). Seedlings of tomatoes were transplanted to the field on 21st of May in both years, at the 75 x 80 cm distance. The experimental design was a randomized block with four replicates for each of the four different nitrogen treatments and the two cultivars, each covering about 18 m^2 area. Harvest of tomatoes was started on 7th of August and ended on 5th September 2014, and on 18th August and 5th October 2015, respectively. Whole yield was divided into total yield (yield of all fruits produced on the plants) and marketable yield (yield of healthy, mature red fruits of diameter above 3.5 cm.). The growing degree days (GDD) ware calculated for periods from transplants planting in the field to the first harvests. It was 79 days (21st May – 7th August) in 2014 and 90 days (21st May – 18th August) in 2015. The base temperature (Tbase) was 12.8 °C, as suggested Battilani *et al.* (2000).

Fully ripen fruits (at least 20 fruits from each treatment for quality analysis) were harvested and immediately analyzed for content of dry matter (by drying up to 102 ^{0}C), soluble solids with the HI-96801 (Hanna Instr.) refractometer, ascorbic acid (by the Thillmans method (ISO, 1984)), lycopene (by a spectrophotometric method (Saniewski and Czapski 1983, Umiel and Gabelman 1971)), soluble polyphenols by the Folin'a-Ciocalteu method (Vinson *et al.* 1998), total flavonoids(by spectrophotometric method (Zhishen *et al.*, 1999, Eberhardt *et al*., 2002), antiradical activity (by the DPPH method (Lee *et al*., 1995)), as well as firmness with the Instron 1140 texturometer and fruit color (Hunter '*Lab')* with the Hunter CQ Spec. Results in Tables 4-7 related to the values of the given components are expressed on a tomato fresh weight basis.

Tomato storage experiments were carried out in 2014 and 2015. In 2014, two storage experiments were conducted. The first experiment was harvested on 26 Aug., while the second harvest was on 5 Sep. In the following year, fruits were picked up on 24 Aug and only one storage experiment was set up. The day after harvest, fruits were washed in tap water at a temperature higher than the temperature of tomato tissues by 5 °C, dried and laid in boxes lined with a polyethylene (PE) film. The storage experiment was set up in 4 replicates of 25 fruits each. Tomatoes were stored for 8 days at 12 °C. Every two days during storage period, the infection by diseases was evaluated, the marketable value was determined as well as the weight loss of fruits were measured. The assessment was performed according to 9-grade scales as explained below:

Marketable Value of Tomato Fruits

9- excellent (as freshly harvested fruits); 7- good (small signs of senescence); 5- satisfactory (minimum usefulness for market, visible signs of senescence); 3- poor (minimum usefulness for consumption, advanced senescence or rotting); 1- bad (not useful for human consumption).

Infection by Diseases

1- lack; 3-light, decreasing of usefulness for market; 5- medium, 7- strong, 9- very strong, completely rotten.

Data were analyzed by means of analysis of variance with year, cultivar, and N dose as the fixed factors. The means were compared using Tukey HSD test at p=0.05.

Multiple regression analysis was done to separate polynomial contrast for each cultivar to characterize the effect of increasing levels of a nitrogen doses on response variables. All calculations were done using Dell Statistica v.13 (Dell Inc. 2016) software package.

RESULTS AND DISCUTIONS

Yield of Tomatoes

Significant interactions were found between the studied years, nitrogen fertilization, and tested cultivars. Year 2015 was more favorable for the cultivation of tomatoes (Table 1). Higher temperatures during growth and fruit ripening and higher sum of GDD extended fruit harvesting in comparison to 2014. A much lower amount of rainfall during the months of July-September in 2015 was supplemented by irrigation. As a result of favorable conditions, the yield of tomatoes was almost twice as high in 2015 compared to 2014. Weather conditions had a big impact, especially in the case of cultivar 'Volna', which in the first year had a significantly lower yield than 'Calista', while in the second year of the study total yield of this cultivar was insignificantly higher than 'Calista'.

Response of tomatoes to fertilizer N doses depended on year and cultivar. In the first year of the study, N fertilization had a significant effect on yield of tomatoes (Table 2). Average yield for both tested cultivars increased significantly for dose of 50 kg N ha^{-1} and higher N doses had no significant effect on yield. There was a significantly different response of tested cultivars to N fertilization. In 2014, quadratic positive regression was found between N rates and yield of cv. 'Calista' (R^2=0.90), and a linear relation for cv. 'Volna' (R^2=0.77). The 'Calista' cultivar also produced significantly higher yield (by 60%) compared to 'Volna' cultivar.

In 2015, tomato yield was also dependent on the applied N fertilization (Table 2). The tomato yield increased with increasing doses of N up to 200 kg N·ha^{-1} and a linear positive regression between N rates and yield was found for cv. 'Volna' (R^2=0.71) and cv. 'Calista' (R^2= 0.44).

The highest total yield of tomatoes, regardless of both tested cultivars, was obtained at a dose of 200 kg N ha^{-1}, but there was no significant difference between 100 and 200 kg N ha^{-1}. There was no significant difference in yield between the tested cultivars.

The share of commercial yield in the total yield ranged from 77.8% for the cv.'Volna' in the control treatment up to 90.4% for the cv. 'Calista' at the dose of 50 kg N·ha^{-1} (Table 2). In both years, the share of marketable yield in the total yield was higher in cv. 'Calista' compared to cv. 'Volna'.

Nitrogen fertilization did not have a clear impact on the share of the marketable yield in the total yield, however, the highest percentage of the marketable yield in the total yield was found with the fertilization rates of 50 and 100 kg N·ha^{-1}.

Results of the present study indicated that yield of tomatoes depended on weather

Table 1. Meteorological data during 2014 and 2015 growing seasons.

	Mean monthly air temperature (ºC)		Monthly sums of precipitation (mm)		Sun radiation (Wm^{-2}) (Mean)		Growing Degree Days (GDD) T_{base}=12.8ºC	
Month	2014	2015	2014	2015	2014	2015	2014	2015
May	14.0	13.5	92.6	34.4	164	155	57.6	7.3
June	16.3	17.4	59.9	38.6	188	183	101.4	111.9
July	20.8	20.2	82.8	37.6	195	191	248.9	205.2
August	17.8	22.3	80.9	19.6	145	197	65.8	62.7
September	14.4	15.2	32.7	26.8	108	113	-	122.9
October	9.2	7.4	7.6	58.8	52	58		
Mean/Total	15.4	16.0	356.5	215.8	142	149.5	473.6	509.9

Table 2. Effect of N doses on total yield [t ha^{-1}] and percentage of marketable yield in total yield of the two tomato cultivars. [a]

N treatment [kg N·ha^{-1}]	2014 Calista t.ha^{-1}	%	2014 Volna t.ha^{-1}	%	Mean	%	2015 Calista t.ha^{-1}	%	2015 Volna t.ha^{-1}	%	Mean	%
0	80.0bA	88,0	67.4aA	81,5	73.7b	85,0	173.8aA	86,5	167.5bA	77,8	170.7b	82,1
50	116.2aA	88,5	75.8aB	79,0	96.0a	80,2	175.5aA	90,4	187.8abA	84,0	181.7ab	87,2
100	131.1aA	89,4	80.3aB	80,9	105.7a	85,1	184.5aA	87,5	196.4abA	83,4	190.5ab	85,4
200	119.2aA	86,3	85.4aB	78,0	102.3a	82,1	191.2aA	88,0	209.7aA	79,0	200.4a	83,5
Mean	111.6A	88,2	77.2B	78,8	94.4B[#]		181.2A	88,1	190.4A	81,0	185.8A[#]	
ANOVA results												
Effect Year (Y)	N (N)		Cultivar (C)		YxN		YxC		NxC		YxNxC	
Significance ***	***		***		NS		***		NS		*	
Polynomial contrast results (Siginificance)												
Linear model	*		***				*		***			
Quadratic	***		NS				NS		NS			
Regression model parameters												
R	0.901		0.771				0.441		0.708			
Equation	Y=80.6+0.84x-0.0033x^2		Y=69.7+0.086x				Y=173+0.093x		Y=173+0.20x			
N_{Max}	127											

[a] Means within each column followed by different lower case letters or within each cultivar followed by different upper case letters are significantly different at the 5% level according to Tukey test. Means followed by different upper case letters with hash concerning year comparisons. N_{Max} - Nitrogen application rate at which the maximal yield was achieved. ***, **, *; 0.001, 0.01, 0.05 ad > 0.05, respectively

condition during plant growth and type of cultivar. Both cultivars produced higher yield in the year with better growing conditions during vegetation period, but cv. 'Volna' was more susceptible to unfavorable conditions than cv. 'Calista', and produced lower yield in 2014. It was also observed that response of tomatoes to N fertilizer doses might depend on both weather condition and cultivar. In 2014, significant increase in total yield regardless of cultivars appeared for dose of 50 kg N ha^{-1}, while in 2015, total yield increased significantly for 100 kg N ha$^{-1.}$ The cultivar response to N doses also varied with year. The yield of cv. 'Calista' significantly increased up to 100 kg N ha^{-1} in both years. In case of cv. 'Volna', yield increased significantly up to 50 and 100 kg N ha^{-1} in 2014 and 2015, respectively. In many experiments with N fertilization of tomatoes, N doses at which highest yields were obtained ranged from 60 up to even 298 kg N ha^{-1} (Iqbal *et al.*, 2011; Ozores-Hamton *et al.*, 2012). The differences in the results obtained were related to the different climatic and soil conditions, the use of irrigation, and cultivar (Kaniszewski and Rumpel, 1983: Kaniszewski *et al.*, 1987; Elkner and Kaniszewski, 1995; Stefanelli *et al.*, 2010; Warner, 2006; Iqbal *et al.*, 2011).

Quality Traits

Results of chemical and physical analysis of tomatoes have shown that quality features such as content of ascorbic acid, lycopene, total flavonoids and antiradical activity, of non- fertilized tomatoes (0 kg N$\cdot$ha^{-1}) depended on cultivar and year of cultivation (Table 3-6).

For cv. 'Calista', the tendency to higher lycopene content in fruits was found in non-fertilized tomatoes in 2015 compared to 2014, but content of total flavonoids and soluble polyphenols seems to be higher in fruits from cultivation in 2014 compared to growing season 2015. Non-fertilized tomato fruits of cv. 'Volna' were characterized in both years of cultivation with lower content of lycopene in comparison to cv. 'Calista'. Fertilization with 50-200 kg N$\cdot$ha^{-1} influenced increase in lycopene content in tomato cv. 'Calista' from 20.11 mg/kg (0 kg N$\cdot$ha^{-1}) up to 36.51 mg$\cdot$kg^{-1} (50-200 kg N$\cdot$ha^{-1}) in 2014, and from 35.41 mg$\cdot$kg^{-1} (0 kgN$\cdot$ha^{-1}) up to 40.44 mg$\cdot$kg^{-1} (50-200 kg N$\cdot$ha^{-1}) in 2015. A similar tendency for changes in lycopene content was observed in case of cv. 'Volna' cultivated in 2014. Similar effects of N fertilization on lycopene content in tomatoes were found in earlier investigations of Di Cesare *et al.* (2010) and Elkner *et al.* (2004). According to Caralampides (2012),

Table 3. Influence of N fertilization on quality traits of fresh tomato cv.'Calista' 2014. [a]

Quality trait	Nitrogen dose [kg N$\cdot$ha^{-1}] 0	50	100	200
Dry matter [%]	5.58 a	5.26 b	5.40 ab	5.26 b
Soluble solids [%]	4.27 a	4.13 a	4.23 a	4.30 a
Ascorbic acid [mg$\cdot$100g^{-1}]	15.15 a	10.94 b	10.70 b	8.31 c
Acidity /pH/	4.57 a	4.63 a	4.60 a	3.97 b
Titratable acidity [mg citric acid$\cdot$100g^{-1}]	0.25 a	0.28 a	0.25 a	0.29 a
Lycopene [mg$\cdot$kg^{-1}]	20.11 b	36.71 a	36.71 a	36.11 a
Soluble polyphenols [mg$\cdot$100g^{-1}]	22.52 a	21.11 a	21.87 a	22.93 a
Total flavonoids [mg$\cdot$kg^{-1}]	48.75 a	42.99 a	17.71 b	16.32 b
Antiradical activity [%]	12.67 b	16.33 a	13.27 b	11.53 b
Fruit redness /Hunter 'a' index/	24.14 c	25.92 b	26.33 ab	27.11 a
Fruit firmness /Newtons/	22.78 a	21.87 a	21.63 a	20.15 a

[a] Means followed by the same letter within each line do not differ significantly at P=0.05 according to the HSD Tukey test.

Table 4. Influence of N fertilization on quality traits of fresh tomato cv. 'Calista'. 2015. [a]

Quality trait	Nitrogen dose [kg N·ha^{-1}]			
	0	50	100	200
Dry matter [%]	6.30 c	7.64 a	6.91 b	6.89 b
Soluble solids [%]	5.40 d	6.40 a	6.10 c	6.30 b
Ascorbic acid [mg·100g^{-1}]	17.26 b	19.23 a	19.49 a	15.41 c
Acidity /pH/	4.92 b	4.92 b	4.99 a	4.99 a
Titratable acidity [mg citric acid·100g^{-1}]	0.26 b	0.28 a	0.23 b	0.24 b
Lycopene [mg·kg^{-1}]	35.41 b	36.86 b	42.25 a	42.21 a
Soluble polyphenols [mg·100g^{-1}]	17.84 c	19.64 c	21.05 b	23.49 a
Total flavonoids [mg·kg^{-1}]	37.40 b	40.03 b	44.59 a	43.51 a
Antiradical activity [%]	6.67 b	9.43 a	7.60 b	7.33 b
Fruit redness /Hunter 'a' index/	28.87 a	28.72 a	27.95 a	28.58 a
Fruit firmness /Newtons/	20.55 b	21.02 b	24.07 a	21.83 b

[a] Statistical differences – see under table no.3.

Table 5. Influence of N fertilization on quality traits of fresh tomato cv. 'Volna'. 2014. [a]

Quality trait	Nitrogen dose [kg N·ha^{-1}]			
	0	50	100	200
Dry matter [%]	5.44 a	5.39 a	5.23 a	5.41 a
Soluble solids [%]	4.23 ab	4.27 ab	4.03 b	4.40 a
Ascorbic acid [mg·100g^{-1}]	12.21 b	16.80 a	11.59 b	9.68 c
Acidity / pH/	3.80 a	4.57 a	4.57 a	4.17 a
Titratable acidity [mg citric acid·100g^{-1}]	0.30 a	0.32 a	0.31 a	0.30 a
Lycopene [mg·kg^{-1}]	16.40 b	20.14 b	16.73 b	28.77 a
Soluble polyphenols [mg·100g^{-1}]	24.76 b	26.14 b	25.28 b	27.89 a
Total flavonoids [mg·kg^{-1}]	36.00 a	32.69 a	43.31 a	34.88 a
Antiradical activity [%]	17.27 a	17.13 a	13.03 b	9.93 b
Fruit redness /Hunter 'a' index/	23.10 b	25.77 a	24.41 b	25.82 a
Fruit firmness /Newtons/	17.11 a	16.22 b	18.27 a	16.10 b

[a] Statistical differences – see under table no. 4.

Table 6. Influence of N fertilization on quality traits of fresh tomato cv. 'Volna'. 2015.

Quality trait	Nitrogen dose [kg N·ha^{-1}]			
	0	50	100	200
Dry matter [%]	6.15 d	7.05 b	7.13 a	6.61 c
Soluble solids [%]	4.70 c	6.30 a	6.30 a	5.30 b
Ascorbic acid [mg·100g^{-1}]	17.82 b	17.65 b	18.81 a	18.16 ab
Acidity /pH/	4.84 b	4.83 b	4.85 ab	4.89 a
Titratable acidity [mg citric acid·100g^{-1}]	0.33 b	0.33 b	0.36 a	0.34 b
Lycopene [mg·kg^{-1}]	11.51 a	10.97 a	11.25 a	9.78 a
Soluble polyphenols [mg·100g^{-1}]	22.07 d	24.00 c	27.04 b	30.52 a
Total flavonoids [mg·kg^{-1}]	42.69 a	34.14 b	42.60 a	44.84 a
Antiradical activity [%]	7.57 a	8.23 a	8.20 a	8.10 a
Fruit redness /Hunter 'a' index/	27.97 a	27.85 a	28.20 a	28.50 a
Fruit firmness /Newtons/	18.12 b	16.08 b	17.47 b	19.48 a

Statistical differences – see under table no. 4.

lycopene content of tomatoes harvested at the earlier date had a quadratic response to increasing N fertilization levels. The highest lycopene content was obtained by applying 90 kg N ha^{-1}; moreover, further increase in the N fertilization as well as a lower rate resulted in a decrease in lycopene content. Other studies have shown that N fertilization has inconsistent effect on lycopene content in tomatoes. Kobryń and Hallmann (2004) observed no significant difference in lycopene content in fruits between N treatments. Aziz (1968) observed a negative correlation between lycopene content in tomatoes and N fertilization rate in cultivation. In a pot experiment, Montagu and Goh (1990) noted increased lycopene content in tomatoes by an average of 30% with different N fertilization. Klein *et al.* (2005) also observed a higher lycopene content in field grown tomatoes when plants were fertilized with organic N, but different levels of lycopene content in fertilized tomatoes were noticed between the years of cultivation. The average content of lycopene for cv. 'Calista' (0-200 kg $N{\cdot}ha^{-1}$) was found to be 32.41 $mg{\cdot}kg^{-1}$ in 2014 and 39.18 $mg{\cdot}kg^{-1}$ in 2015. There was opposite situation in case of cv. 'Volna' (0-200 kg $N{\cdot}ha^{-1}$) where an average content of lycopene - 20.51 $mg{\cdot}kg^{-1}$ - in 2014 was higher than lycopene content in 2015 (10.88 $mg{\cdot}kg^{-1}$) by almost 100 %. It was also found that tomatoes of cv. 'Calista' cultivated in 2015 were characterized with average lycopene content of 39.18 mg/kg F.W. and Hunter's 'a' index of fruit redness was 28.52, but tomato fruits grown in 2014 contained lycopene at average level of 32.41 $mg{\cdot}kg^{-1}$ and redness index 'a' of 25.88.

The range of ascorbic acid content in tomatoes cultivated in the year 2014 (11.28 – 12.57 $mg{\cdot}100g^{-1}$) was different from that in 2015 (17.85 – 18.11 $mg{\cdot}100g^{-1}$). The influence of N fertilization on ascorbic acid content in tomatoes was inconsistent, as in 2015, the rate 50-100 kg $N{\cdot}ha^{-1}$ influenced increase in ascorbic acid content in tomato cv. 'Calista', but in 2014, the opposite effect was noticed**.** Shinohara *et al.* (2007) studied the effects of foliar spray treatment with N and other nutrients on the ascorbic acid content of tomato and sweet pepper fruits. They found that ascorbic acid content of tomato fruits was not affected by the N treatments, with the exception of the increased potassium rate which gave a remarkably high ascorbic acid content. In very early experiments of Somers *et al.* (1951), tomatoes were grown in sand culture with varying amounts of nitrogen supplied as nitrate before and after onset of ripening. They indicated that nitrate supply for the month prior to the onset of ripening influenced ascorbic acid content of the fruits and fruit production. The nitrate supply after the onset of ripening influenced neither fruit production nor the ascorbic acid content of the fruits produced. High nitrate supply was associated with high fruit production, but with low ascorbic acid content. Moreover, it was found that the ascorbic acid content of the fruits at the last harvest was associated with the degree to which they were shaded.

Soluble solids content in tomatoes is especially important for processing fruits. Cultivar 'Calista' - designated for processing - was characterized with average content of soluble solids 6.05% in 2015 compared to average of 4.23% for tomatoes from cultivation in 2014. The tomatoes fertilized with 50-200 kg $N{\cdot}ha^{-1}$ of both cultivars grown in 2015 showed somewhat higher soluble solids content (av. 6.27% for cv. 'Calista' and av. 5.97% for cv. 'Volna') in comparison to non-fertilized (0 kg $N{\cdot}ha^{-1}$) tomatoes (5.40% for cv. 'Calista' and 4.70% for cv. 'Volna'). In 2014, the tomatoes fertilized with 50-200 kg $N{\cdot}ha^{-1}$ of both tomato cultivars had the same soluble solids content in fruits i.e. 4.23%. There was no effect of increasing level of N fertilization from 50 to 200 kg N ha^{-1} on soluble solids content, in agreement with Warner *et al.* (2006). Frias-Moreno *et al.* (2014) reported that the dosages of N fertilizer increased soluble solids in tomato fruits grown in greenhouse condition. According to Qi *et al.* (2005), slight increase in content of soluble solids in tomato fruits can be observed after a second application of N during fruit formation. Benard *et al.* (2009) has found that lowered nitrogen supply had a low impact on fruit commercial yield, but it reduced plant vegetative growth and increased fruit dry matter content, consequently, improving fruit quality.

Increasing rates of N fertilization in the year 2015 significantly affected the soluble polyphenols content both cultivars 'Calista' and 'Volna'. The initial level of soluble polyphenols 17.84 and 22,07 $mg^{.}100g^{-1}$ in non-fertilized cv. 'Calista' and cv. 'Volna' increased, respectively, up to 23.49 and 30.52 $mg^{.}100g^{-1}$ in fertilized (200 kg N ha^{-1}) tomatoes. In cultivation in 2014, the same trend was observed only for cv. 'Volna'. Also, Zhang *et al.* (2016) found that higher levels of N fertilizer and organic fertilizer can increase the content of phenols in tomato fruits. Among all phenolic acids, coffeic acid was found to be at the highest levels. On the other hand, El-Mergawi *et al.* (2014), in greenhouse experiments, proved that phenolics content as well as antioxidant capacities in tomato fruits were not significantly affected by the high N rates applied (150, 300 and 450 kg $N^{.}$ ha^{-1}). These authors also tested the effect of different forms of N on phenolics and antiradical activity of tomatoes. It was observed that tomatoes treated with calcium nitrate or ammonium sulfate had higher phenolic and ascorbic acid contents than plants treated with ammonium nitrate or urea. Studies of Luthria *et al.* (2006) revealed an increase in total phenols and phenolic acid content in tomatoes when grown in a high tunnel that transmitted the full range of ambient solar UV radiation from 290 to 400 nm as compared to samples from plants grown in a high-tunnel lacking UV wavelengths at 380 nm and below.

The highest antiradical activity of tomato fruits cvs. 'Calista' and 'Volna' was found for plants fertilized with 50 kg N ha^{-1} irrespective of the cultivation year. With the increase in N fertilization, the antiradical activity level showed a tendency to decrease. Borguini *et al.* (2013) compared the effect of organic and conventional cultivation on the antioxidant compound content and antioxidant activity of the tomatoes. They showed that extracts from organic tomatoes presented higher antioxidant activity in the DPPH test than the conventional tomatoes. Authors suggest that organic tomatoes had higher antioxidant potential probably due to its higher ascorbic acid and total phenolic content. According to Verma *et al.* (2015), the increase in antioxidant activity in tomatoes by 24–63% can be achieved by application of compost with effective microorganisms and half of recommended rate of chemical fertilizers as compared to the application of recommended dose of only chemical fertilizers. At the same time, tomato quality can be improved in terms of increase in lycopene content by about 35 % in this treatment.

The physical parameters of tomato quality in cv. 'Calista' and cv. 'Volna' i.e. the Hunter 'a' indexes of fruit redness and fruit firmness, varied depending on the year of cultivation. Slight increase in redness index was observed in 2014 for fertilized tomatoes of both cultivars (from 50 up to 200 kg $N^{.}ha^{-1}$) in comparison with non-fertilized tomatoes. Moreover, the average indexes of redness of tomato fruits cv. 'Calista' -25.88 and 'Volna' – 24.78 coming from cultivation in 2014 were lower than in 2015 as, respectively, 28.52 and 28.19. The average fruit firmness of cv. 'Calista' in 2014 (21.61 N) was similar to that in year 2015 (21.87 N) and, at the same time, these values were higher in comparison to cv. 'Volna', 16.92 N (2014) and 17.79 N (2015), respectively. No significant differences in fruit firmness between tomatoes grown under increasing N rates were found. Warner *et al.* (2006) also studied the effect of similar N fertilization (50 -200 kg $N^{.}ha^{-1}$) on color and firmness of tomatoes and they observed no changes in firmness and color of marketable fruits. In pot experiments of Javaria *et al.* (2012), significant relationships were apparent between potassium fertilizer rates and surface redness, tissue redness, and fruit firmness. They concluded that increasing K

Table 7. The influence of N fertilization on marketable value of tomato fruits during 8 days at 12 °C (average of two experiments in 2014). [a]

Nitrogen dose [kg N·ha^{-1}]	Length of the storage period [days]							
	cv. 'Calista'				cv. 'Volna'			
	2	4	6	8	2	4	6	8
0	8.9	8.6	7.5	6.7 b	8.4	7.4	6.2	4.8
50	8.8	8.6	7.8	6.9 ab	8.3	7.3	5.9	4.8
100	8.9	8.7	8.1	7.2 ab	8.3	7.5	6.1	5.1
200	8.9	8.6	8.2	7.6 a	8.5	7.5	6.1	4.9

[a] Marketable value: 9: excellent, 7: good, 5: satisfactory, 3: poor, 1: bad. Means followed by the same letter within each column do not differ significantly at P=0.05 according to the HSD Tukey test.

Table 8. Infection of tomato by diseases during 8 days at 12 °C (average of two experiments in 2014). [a]

Nitrogen dose [kg N·ha^{-1}]	Length of the storage period [days]							
	cv. 'Calista'				cv. 'Volna'			
	2	4	6	8	2	4	6	8
0	1.1	1.5	2.5	3.3 d	1.5	2.5	3.8 a	5.1
50	1.2	1.5	2.3	3.0 c	1.7	2.7	4.1 b	5.1
100	1.2	1.4	1.9	2.8 b	1.8	2.5	3.8 a	4.8
200	1.2	1.4	1.8	2.4 a	1.5	2.5	3.8 a	5.0

[a] Infection by diseases: 1: lack, 3: slight, decreasing suitability for market, 5: medium infestation, 7: strong, 9: very strong, completely rotten. Statistical differences – see under Table 7

Table 9. The influence of N fertilization on marketable value of tomato fruits during storage at 12 °C (average of one experiment in 2015). [a]

Nitrogen dose [kg N·ha^{-1}]	Length of the storage period [days]									
	cv. 'Calista'					cv. 'Volna'				
	2-12	14	16	18	20	2-12	14	16	18	20
0	9.0-8.7	8.4	8.3	7.9	7.4	9.0-7.8	7.2	6.7	6.0	5.7
50	9.0-8.8	8.5	8.3	7.9	7.3	9.0-7.9	7.6	7.3	6.5	6.1
100	9.0-8.7	8.5	8.2	7.7	7.3	9.0-7.3	7.1	6.7	6.0	5.3
200	9.0-8.8	8.5	8.5	8.0	7.6	9.0-8.0	7.7	7.2	6.4	6.0

[a] Marketable value – see under Table 7.

Table 10. Infection of tomato by diseases during storage at 12 °C (average of one experiment in 2015). [a]

Nitrogen dose [kg N·ha^{-1}]	Length of the storage period [days]									
	cv. 'Calista'					cv. 'Volna'				
	2-12	14	16	18	20	2-12	14	16	18	20
0	1.0-1.2	1.4	1.6	2.1	2.5	1.0-2.2	2.7	3.1	4.0	4.3
50	1.0-1.2	1.5	1.7	2.1	2.7	1.0-2.0	2.4	2.6	3.4	3.9
100	1.0-1.3	1.6	1.8	2.3	2.7	1.0-2.5	2.9	3.2	3.8	4.6
200	1.0-1.2	1.5	1.6	2.1	2.4	1.0-1.8	2.2	2.7	3.6	4.0

[a] Infection by diseases- see under Table 8.

concentration resulted in improved quality parameters of tomato fruits and application of suitable amount of K_2O per ha along with recommended doses of N and P was found to be the best dose for high quality tomato fruits.

Storage Ability

Tomato fruits taken for the storage tests were characterized with poor storage ability in 2014 and rather good in 2015. In the first experimental year, fruits retained very good appearance only during 2- 4 days (depending on the cultivar), while in the 2015, during 10 – 16 days. These results confirm the earlier observation of Genanew (2013) that the differences in post-harvest losses of tomatoes depend on their seasonal weather conditions. Weather conditions varied significantly in experimental years, particularly during period of growing and ripening of tomato fruits. In August 2014, the average temperature was 17.8°C and total precipitation was 80.9 mm, while in 2015, these values were 22.3°C and 19.6 mm (Table 1), respectively. The main reason of storage life shortening in 2014 was high infection by diseases leading to rotting of the fruits. Also, in reports of Vinha *et al.* (2013) and Abiso *et al.* (2015), pathogen infection was listed as one of the main factors limiting the storage of tomatoes. The weather condition with frequent and heavy rains in 2014 was very favorable for the development of fungal diseases during the growing season, which resulted in higher rotting during storage.

The level of N fertilization in the range 0 - 200 kg N·ha^{-1} had significant influence on tomato fruits quality during short-term storage only in 2014 and for one cultivar (‘Calista’). The results obtained after 8 days of storage showed increase in resistance to disease and thus slightly better storage ability of tomato fruits with increasing N fertilization during growing season. In 2015, after 16 days of storage, tomatoes maintained insignificantly higher quality in the treatment with the highest dose of N (200 kg) in comparison to lower N fertilization. The positive influence of N fertilization on storage ability of tomato fruits was reported earlier by Sainju *et al.* (2003) and Cesare *et al.* (2010). Bartz *et al.* (1979) presented opposite dependence, because in their study the susceptibility to disease had increased with increasing N fertilization.

The storage ability of tomato cv. ‘Volna’ was significantly lower than cv. ‘Calista’. In the case of tomato cv. ‘Volna’, the obtained results of marketable value and infestation by disease do not allow to conclude that the use of different N doses during cultivation affect the storage ability of the fruits after harvest. Generally, the differences of senescence rates among all experimental treatments were low and proceeded in different ways in each of the three experiments. According to De Ketelaere *et al.* (2004), the quality traits are highly dependent on cultivar. The natural weight losses during tomato storage were very low and did not exceed 1.7 % after 8 days of storage in 2014, and after 20 days of storage in 2015.

CONCLUSIONS

A significant effect of the year and N fertilization was found on the yield of the tested tomato cultivars. Depending on the year, yield increased significantly for doses of 50 to 100 kg N ha^{-1}. The chemical and physical parameters of tomato quality varied depending on the year of cultivation. On average, for the studied years and cultivars, increasing N fertilization increased lycopene and soluble polyphenols content, but decreased total flavonoids, ascorbic acid content, and antiradical activity. Nitrogen rate did not affect dry matter and soluble solids content, fruit firmness, fruit redness, and acidity. Cultivar ‘Calista’ had significantly higher lycopene content and better fruit firmness than cv. ‘Volna’ for fresh market. Furthermore, the storage ability of tomatoes cv. ‘Calista’ was significantly better than cv. ‘Volna’. N rates had a slight and rather positive effect on storage ability of tomato fruits.

Funding Sources

This study was developed within the SUNNIVA project of the European framework ERA-NET SUSFOOD and supported by the the National Center for

Research and Development (NCBiR)–Poland, the Daniel and Nina Carasso Foundation, France (www.fondationcarasso.org) and the Italian Ministry of Agriculture Food and Forestry Policies (MIPAAF).

ACKNOWLEDGEMENT

The authors would like to thank Assoc. Prof. Robert Maciorowski for his statistical expertise.

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تاثیر کولتیوار و مقدار مصرف نیتروژن بر عملکرد و صفات کیفیتی گوجه فرنگی مزرعه ای

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چکیده

این پژوهش به منظورتعیین اثر کوددهی نیتروژن (N) بر عملکرد و صفات کیفیتی و انبارداری دو کولتیوار گوجه فرنگی به نام های Calista (مخصوص فرآوری) و Volna (برای تازه خوری) طی سال های ۲۰۱۴ و ۲۰۱۵ انجام شد. مقدار مصرف N برابر ۰، ۵۰، ۱۰۰ و ۲۰۰ کیلوگرم در هکتاربود. نتایج آزمایش از عکس العمل معنادار سال، کوددهی N و کولتیوار حکایت داشت. در سالی که شرایط

کشت ورشد در طی دوره سبزینگی خوب بود، هر دو کولتیوار مطالعه شده عملکرد بالا ومشابهی نشان دادند. در سالی که شرایط آب وهوایی نامساعد بود(درجه حرارت پائین تر، بارندگی کل بیشتر، و GDD کوچکتر) عملکرد کولتیوارVolna به طور معناداری کمتر از Calistaشد. کوددهی N تاثیری معنادار بر عملکرد داشت، هرچند که واکنش کولتیوارها در هر سال تغییر میکرد. در سال ۲۰۱۴، یک رگرسیون مثبت درجه دو بین مقدار مصرفN و عملکرد Calista (با R^2=0.90) و یک رابطه خطی باVolna (با R^2=۰.۷۷) به دست آمد. اما در سال ۲۰۱۵، رابطه برای کولتیوارVolna (R^2=0.71)وCalista (R^2= 0.44) به صورت خطی بود. پارمترهای شیمیایی و فیزیکی کیفیت گوجه فرنگی به سال کشت محصول وابسته بود و تغییر میکرد. به طور میانگین، برای سالهای مطالعه و کولتیوارهای آزمایشی، افزایش مقدار کود N بر محتوای لایکوپین و پلی فنل های محلول و نیز کل فلاونوئیدها و محتوای اسکربیک اسید و فعالیت آنتی رادیکال اثر گذاشت ولی بر ماده خشک و موادجامد محلول، سفتی میوه، قرمزی میوه و اسیدیته بی اثر بود. مقدار لایکوپین و نیز سفتی میوه در کولتیوار Calistaبه طور معناداری بیشتر و بهتر از Volna برای تازه خوری بود. افزون بر این، قابلیت انبارداری گوجه فرنگی کولتیوار Calistaبه طور معناداری بهتر از Volna بود.