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ALTERATION OF YIELD AND QUALITY OF TOMATO FRUIT BY CONVENTIONAL AND ORGANIC CROP MANAGEMENT

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In this research, the yield and qualitative parameters of tomato cultivar Hector F1 grown in various fertilization and plant protection treatments in two successive growth seasons were investigated. Estimation of fertilization and protection impact on the properties of tomato fruits was carried out using a two-factor ANOVA test, whilst correlation between individual parameters was conducted using a heatmap. Tomato yield was significantly lower in the control compared to the fertilized and chemically/biologically protected tomato, whilst significant differences in yield were not observed between the fertilized and protected treatments. The mean total soluble solids and fruit acids were most pronounced in the treatment with chemical fertilizers and biological protection, whilst the highest vitamin C content was observed in the control. The highest K and Cu content was observed in the organically fertilized and biologically protected tomato. A clustergram showed a positive correlation between the three groups of parameters: i). nitrates, vitamin C and total N; ii). fruit acids, total soluble solids and Cu; and iii). other parameters. To our knowledge, this is the first report on the combined effects of fertilizers and plant protection products on tomatoes grown in conventional and organic systems.
Keywords: conventional production, crop management, quality, organic production, tomato, yield.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the main crops worldwide and an important reservoir of vitamins, antioxidant compounds, phenolics, flavonoids etc. (Riahi and Hdider, 2013). Tomato fruit is commonly used in the human diet and provides about 40% of a persons daily vitamin C intake, while lycopene, as well as others antioxidant compounds are capable of reducing the risk of certain chronic diseases (Ochoa-Velasco *et al.,* 2016).
It is evident that the antioxidant content in tomato fruits is linked to various factors, such as inadequate use of agrochemicals during vegetation (Rossi *et al.,* 2008; Cardoso *et al.,* 2011). These long-term conventional practices in agricultural systems play a large part in the process of ecosystem pollution; more than 70% of N fertilizers are lost for plant nutrition, which represents an unacceptable loss for agricultural lands (Souri and Yarahmadi, 2016). Thus, a more sustainable approach to agricultural production requires more sound and environmentally friendly practices coupled with the improvement of the yield quality and quantity (Russo *et al.,* 2012; Struik and Kuyper, 2017; Nguyen and Thinh, 2020).
The reduction of pesticide use and chemical fertilizer application in agriculture can be fostered through the application of a variety of protein-based products (Calvo *et al.,* 2014), such as amino acids. These organic molecules can play a significant role in the improvement of tomato plant yield and quality in greenhouses (Sadak *et al.*, 2015). Similar results can also be achieved using microbial based inoculants (Berg, 2009). Approximately one-third of the total microorganisms isolated from plant cover habitats showed the capability of inhibition growth of plant pathogens (Berg *et al.,* 2006), while two-thirds showed a plant growth promoting (PGP) capacity (Fürnkranz *et al.*, 2009). Application of microbial inoculants has risen highly in the past several past decades as a solution to environmental problems in agricultural production (Hayat *et al.,* 2010). The most successful plant growth promoting rhizobacteria (PGPR) used on a commercial scale belongs to genera *Azospirillum*, *Pseudomonas* and *Bacillus* (Babu *et al.,* 2015), whilst the *Trichoderma* species, known as plant growth promoting fungi (PGPF), were also used in the biocontrol of several phytopathogens (El-Komy *et al.*, 2015).
Apart from having an effect on plant development, microbial inoculants may have significant impact on the activity of soil

microbes (Kozdroj *et al.*, 2004; Suyal *et al.*, 2016), which participate in nutrient accumulation around the root (Ambrosini *et al.*, 2016). Microbial inoculants may also be used in conventional agricultural production, but it is necessary that they are compatible with agrochemicals used during crop growth (Calvo *et al.*, 2014).

Taking into account the importance of tomato fruit in human nutrition, the aim of this paper was to estimate the impact of chemical and biological fertilizers, as well as chemical and biological pesticides on microbial activity within the soil, tomato yield and quality.

MATERIALS AND METHODS

The experiment was carried out in the village Hodbina, within the Mostar municipality, Bosnia and Herzegovina (N 43°14' E 7°51', altitude 47 m), during two successive seasons: 2013 and 2014. This location is characterized by a typical Mediterranean climate (Table 1).

Chemical analyses of soil in the greenhouse were performed before the planting of tomato seedlings in 2013. A composite sample was prepared from individual soil samples passed through a 2 mm diameter mesh sieve. The pH of the composite sample (in H_2O and KCl) was determined using a pH-meter WTW pH 597 (Germany), total N by Kjeldahl method (Bremner, 1996), humus content by Kotzman method (JDPZ, 1966), and available P and K by Al method (Egner *et al.*, 1960). The results indicate that the soil sample was slightly acid to neutral (pH in H_2O 6.92; pH in KCl 6.15), with a low humus (1.70%) and P (9.80 mg 100 g^{-1} of soil) content, and sufficient content of total N (0.190%) and available K (19.70 mg 100 g^{-1} of soil). Based on these results a fertilization program during tomato cultivation was designed. Composite samples from each treatment were taken twice in each season. The first sampling was carried out before the seedling planting and for a second time after the fourth harvest of tomato fruits (29 June 2013, and 19 June 2014). Sampling was performed from a depth of 0 cm through 20 cm. 0.1xTSA (Torlak, Serbia), Rose Bengal streptomycin agar (Peper *et al.*, 1995), Fyodorov agar and starch-ammonia agar were sterilized by autoclaving (Sutjeska, Serbia, 1990) at 120°C and 1.5 bar for 20 minutes and used for the determination of the total number of bacteria (TNB), fungi (F), *Azotobacter* sp. (AZ) and actinomycetes (AM), respectively. The experiment was performed in triplicate. Soil moisture was determined by oven (Binder, Germany) drying at 105°C for 2 h. The number of microorganisms was expressed as colony forming units (CFU) per gram of dry soil sample. Dehydrogenase activity (DHA) was measured by previously described method (Casida *et al.*, 1964) and expressed as μg TPF g^{-1} h^{-1}.

Tomato seeds of cultivar Hector F1 were obtained from a local distributor. For seedlings growth, a commercial substrate Potgrond H (Klasmann, Germany) was used. The sowing of the seeds was performed in January 2013 and 2014, respectively, using plastic containers. Uniform seedlings were transferred to the greenhouse (area 360 m^2, east-west orientation) on April 3, 2013, and March 11, 2014, respectively. Planting was performed in double rows, with a spacing between plants within the rows of 50 cm, a spacing between the two rows comprising a double row of 40 cm and a spacing between double rows of 80 cm.

Four treatments were included in this research: I) chemical fertilization and chemical plant protection (CFCP); II) chemical fertilization and biological plant protection (CFBP); III) organic fertilization and chemical plant protection (OFCP); and IV) organic fertilization and biological plant protection (OFBP). In chemical fertilization treatments, in both years, NPK (MS Biotech, Italy) 13:40:13 (30kg/ha); 20:20:20 (30 kg/ha); 15:30:15 (30 kg/ha); 15:15:15 (50 kg/ha); and 15:05:30 (50 kg/ha) were applied 0-15; 15-30; 30-45; 45-60; and 60-90 days after planting, respectively. Other than NPK fertilizers, Quix Total (containing 4% Fe, Mn 2%, Zn 0.3%, B 0.6%, Cu 0.8 %, and Mo 0.3%, w/w) and Nextra, containing 10% of organic C soluble in water, 95% of humified organic C, and 3% of organic N (Puccioni S.p.A., Italy), Proplant, consisting of 722 g l^{-1} of propamocarb-hydrochloride) and Pyrus 400 SC, consisting of 400 g L^{-1} of pyrimethanil (Agriphar, Belgium), Acrobat MZ 69 WG (dimethomorph and mancozeb), Signum (Boscalid 25.2 % + Pyraclostrobin 12.8 %) and Fastac, consisting of 100 g/l of alpha-cypermethrin (BASF, Germany), Confidor 200 SL (imidacloprid 17.8 % w/w) and Serenade, containing pure cultures of *Bacillus amyloliquefaciens* strain QST 713 (Bayer AG, Germany), MgS, consisting of 16 % MgO + 32.5 % SO_3 (Yara, UK), Ridomil Gold (4 % metalaxyl-M and 64 % Mancozeb) and Aktara 25 WG, consisting of thiamethoxam 25 % (Syngenta, Switzerland), Ranman 400 SC, consisting of cyazofamid (SummitAgro, USA), LabiCuper, consisting of 8 % (w/v) of organic Cu (Macasa, Spain), Kraft 18 EC, consisting of 17 g L^{-1} of abamectin (Cheminova A/S,

Table 1. Temperature, rainfalls, sunshine duration, and humidity data recorded by weather station in Mostar (Bosnia and Herzegovina).

Year	Average annual temperature (°C)	Extreme temperature (°C)		Rainfalls (mm/m^2)		Sunshine duration (h)	Average relative humidity (%)
		Minimum	Maximum	Total	During vegetation		
2013	15.8	-2.4	41.1	2188.3	939.8	2464.2	66
2014	15.8	-4.7	35.6	1782.9	678.9	2288.3	75
1961-1990	14.5	-10.0	41.2	1523.0	576.0	2286.5	62

Denmark), Neoram, consisting of Cu from Cu-oxychloride 375 g kg^{-1} (Adama, Israel), Naturalis, containing spores of *Beauveria bassiana* ATCC 74040 (OHP, USA), Ilsamin, consisting of 8.9 % of organic N, 8.9 % of soluble organic N, 25 % of organic C, and > 10 % of free amino-acids (ILSA S.p.A., Italy), Remedier (Gowan S.r.l., Italia), containing spores of *Trichoderma gamsii* icc 080 (2 %) and *T. harzianum* icc 012 (2 %), Mycosin, consisting of aluminium sulphate, and Amino Vital, containing 50 % of amino-acids (Biofa AG, Germany) were used in 2013 and 2014 according to the manufacturer's instructions (Tables 2 and 3).

A drip irrigation system was used for water supply, approximately 8-10 l/m^2 every two days. To reduce plant evapotranspiration and decrease soil temperature during summer, an agricultural sunshade net (Partner agrocentar, Bosnia and Herzegovina) was used. To reduce pest incidence in the greenhouse, yellow and blue sticky plates were used and placed at 2 m height at several points in the greenhouse. During both seasons, disease and pest incidence were registered. Fruits of the tomatoes were harvested every 3-5 days from June 17th to July 20th in the first season (2013) and from June 4th to July 21st in the second season (2014). In both seasons, harvesting was performed during the stadium of the physiological ripeness of fruits. Research was carried out in a randomized block design in four replications and 10 plants per replication. In the control treatment, neither agrochemicals nor biological protection products/organic fertilizers were used.

Tomato fruits of a similar maturity which originated from the fourth harvest (2nd flower branch) were used for fruit analysis. Fruits in each replication within the treatment were harvested manually and transported quickly to the laboratory. After washing and cutting into small pieces, chemical characterization of the tomato fruits was conducted.

The content of total soluble solids (TSS) was determined using a hand refractometer RHB 32 ATC (Huake Instruments Co., Ltd, China). Organic acids (OA) were determined by titration with 0.1 M NaOH (OECD, 2009). Vitamin C content (VC) was measured using iodometric titration (Haan, 2015), and lycopene (L) content using Hyman *et al.* (2004) method. The measurement of total nitrogen (N) and nitrates were performed according to BS EN 12135 (1998), and ISO

Table 2. Fertilization and protection program used in tomato cultivation during 2013.

Treat-ment	Days after planting				
	0-15	**15-30**	**30-45**	**45-60**	**60-90**
CFCP	Quix Total, Proplant, Akrobat, Confidor	MgS, Quix Total, Ridomil, Ranman, Actara, LabiCuper	MgS, Quix Total, Ranman	MgS, Quix Total, Pyrus	Floral K, Quix Total, Ranman, Actara, Pyrus, Ridomil, Kraft
CFBP	Quix Total, Remedier, LabiCuper	MgS, Quix Total, LabiCuper, Neoram	MgS, Quix Total, Mycosin	MgS, Quix Total, Serenade	Floral K, Quix Total, LabiCuper, Neoram, Serenade, Naturalis
OFCP	Nextra, Proplant, Acrobat, Confidor	Amino Vital, Ridomil, Ranman, Actara, LabiCuper	Amino Vital, Ranman	Amino Vital, Ilsamin, Pyrus	Amino Vital, Ilsamin, Ranman, Actara, Pyrus, Ridomil, Kraft
OFBP	Nextra, Remedier, LabiCuper	Amino Vital, LabiCuper, Neoram	Amino Vital, Mycosin	Amino Vital, Ilsamin, Serenade	Amino Vital, Ilsamin, LabiCuper, Neoram, Serenade, Naturalis

Table 3. Fertilization and protection program used in tomato cultivation during 2014

Treat-ment	Days after planting				
	0-15	**15-30**	**30-45**	**45-60**	**60-90**
CFCP	Quix Total, Proplant, Akrobat, Confidor	MgS, Quix Total, Ridomil, LabiCuper	MgS, Quix Total, Ridomil, Signum, Actara	Ridomil, Signum, Actara	Quix Total, Pyrus, Fastac, Acrobat, Actara, Ridomil
CFBP	Quix Total, Remedier, LabiCuper	MgS, Quix Total, LabiCuper	MgS, Quix Total, Mycosin	Mycosin	Quix Total, LabiCuper, Neoram, Serenade, Naturalis
OFCP	Nextra, Proplant, Acrobat, Confidor	Amino Vital, Ridomil, LabiCuper	Amino Vital, Ilsamin, Ridomil, Signum, Actara	Amino Vital, Ilsamin, Pyrus	Amino Vital, Ilsamin, Pyrus, Fastac, Acrobat, Actara, Ridomil
OFBP	Nextra, Remedier, LabiCuper	Amino Vital, LabiCuper	Amino Vital, Ilsamin, Mycosin	Amino Vital, Ilsamin, Mycosin	Amino Vital, Ilsamin, LabiCuper, Neoram, Serenade, Naturalis

6635:1984 (1984) method, respectively. Contents of P, K, Mg, Fe, Zn and Cu were measured using the Agilent 7700x ICP-MS technique (Agilent Technologies, USA). 2A calibration standard solution (Agilent Technologies, USA) was prepared prior to analysis in 0.5% HCl and 2.0% HNO_3 (Suprapur grade, Merck, Darmstadt, Germany). Digestion of samples was performed using Microwave MDS-8 (Sineo, China) following manufacturer`s instructions in three steps: step 1 on 130ºC for 10 min at 400 W; step 2 on 150 ºC for 5 min at 400 W, and step 3 on 190 ºC for 15 min at 400W.
After each harvest, weight and width of fruits and yield were measured independently as responses to used treatments.
A two-factor (treatment and year) ANOVA were used for the estimation of fertilization and protection impact on the morphological and qualitative properties of tomato fruits. Small letters were used for determination of differences between the years, whilst caps letters for determination of differences between the treatments. If mean comparisons were expressed by the same letter, the differences were not significant. For post-hoc comparison, Duncan test ($p<0.05$) was used.
The study of the similarity of individual treatments as well as the correlation between individual parameters was carried out using a heatmap. This map uses color to represent a third dimension. Each row of the data matrix corresponds to one treatment, whilst the columns correspond to the individual parameters. The matrix elements are the mean values of the individual parameters per treatment. Before clustering, data are standardized at zero average and unit deviation. The distance of individual objects was determined by the euclidean distance, while the Pearson correlation coefficient was used to determine the similarity of individual parameters. The hierarchical clustering algorithm used is based closely on the average-linkage method. Matlab R2017a software was used for the purpose of heatmap creation.

RESULTS AND DISCUSSION

Soil microbes are a key factor for plant development; they possess various metabolic pathways to transform organic into available forms. Soil microbial activity depends on the time of sampling and cultivation treatments (Table 4).
It is evident that in most of the treatments, microbial prevalence in the second season is higher compared to the first season. During tomato cultivation the total microbial abundance increased up to the seventh tomato monoculture (Fu *et al.*, 2017). It is obvious from Table 5 that bacteria represented the most abundant microbial population during our research. Compared to the control, lower microbial activity was noticed in most of the samples which underwent chemical fertilization treatments. Similar observations have been reported previously (Lazcano *et al.*, 2013). Also, the use of pesticides inhibits microbial activity in most of the samples, especially *Azotobacter* sp. and actinomycetes. Up to date, the disruption impact of pesticides on nitrogen fixation (Potera, 2007) and actinomycetes (Tortella *et al.*, 2013) is well documented. A similar effect of pesticides on DHA was described previously (Radivojevic *et al.*, 2008), which is confirmed in our study.

Table 4. Soil microbial and enzyme activity during tomato cultivation.

Year/ Treatment	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**
	TNB		**F**		**AZ**		**AM**		**DHA**	
	($CFUx10^6/g$)				**($CFUx10^3/g$)**				**($x10^{-5}$ µgTPF/g/h)**	
Before planting	5.9	7.8	45.6	25.4	31.6	12.1	31.2	52.6	4.6	6.2
CFCP	5.4	18.8	21.1	47.6	8.7	17.5	43.1	32.0	4.9	5.3
CFBP	5.8	10.1	43.7	30.7	18.8	50.0	35.2	22.5	6.9	8.0
OFCP	3.4	19.5	20.1	40.3	7.0	18.0	28.9	24.6	3.4	4.8
OFBP	6.0	17.3	57.2	38.7	8.8	21.2	33.7	29.7	8.9	9.4
Control	6.1	14.9	22.5	57.9	14.8	11.0	50.9	43.0	8.0	9.6

Legend: Total number of bacteria (TNB), fungi (F), *Azotobacte*r sp. (AZ), actinomycetes (AM), dehydrogenase activity (DHA)

Table 5. Mean yield per harvest (Y), weight and width of tomato fruits.

Year/ Treatment	**2013**	**2014**	**Ave-rage**	**2013**	**2014**	**Ave-rage**	**2013**	**2014**	**Ave-rage**
	Y (t/ha)			**Weight (g)**			**Width (cm)**		
CFCP	8.51bB	4.09aB	6.30	234.22bA	189.22aA	211.72	7.10bA	6.10aA	6.60
CFBP	8.56bB	4.39aB	6.47	259.33bA	174.66aA	219.99	6.89bA	6.16aA	6.52
OFCP	7.95bB	5.06aC	6.50	234.22bA	197.55aA	215.88	6.92bA	6.24aA	6.58
OFBP	8.52bB	4.02aB	6.27	236.77bA	183.55aA	210.16	6.88bA	6.16aA	6.52
Control	4.44bA	3.22aA	3.83	218.11bA	175.44aA	196.77	6.71bA	5.87aA	6.29
Average	7.60	4.16	5.88	236.53	184.08	212.67	6.90	6.11	6.50

Several agricultural practices, such as the use of biofertilizers, may stimulate plant growth (Ambrosini *et al.*, 2016). However, sporadic incidences of several pests and pathogens were noticed in our research. In 2013, due to favourable climatic conditions, incidences of *Tetranychus urticae* presence in the control and BP treatments were recorded. However, after the application of Naturalis in the BP treatments, a suppression of *Tetranychus urticae* growth and expansion was noticed. In the control a high incidence of *Tetranychus urticae* and *Alternaria* sp. was registered, causing serious damage to leaves and fruits. In June 2014, due to extremely large amounts of rainfall, incidences of *Phytophthora infestans* presence were recorded in the control and BP treatments, causing a yield reduction of 20 to 30%. Unfortunately, application of LabiCuper, only led to a slight reduction of *Phytophthora infestans* presence. On the other hand, in the CP treatments, due to preventive pesticide applications, neither pest nor plant pathogens were noticed.

Our results showed that the yield per harvest, weight and width of tomato fruit varied from 3.22 to 8.56 t/ha, 174.66 to 259.33 g, and 5.87 to 7.10 cm, respectively (Table 5).

For the Hector F1 cultivar, there was no significant difference in fruit width between the treatments and control. In contrast to our trial, significantly higher width of ripe tomato fruit was noticed in conventional cultivation compared to organic (Oliveira *et al.*, 2013). Significant differences in tomato yield between the treatments were not recorded. Souri *et al.* (2017) found no significant differences in tomato yield treated by amino-products and NPK fertilizers. Several aminoacids may stimulate, whilst other contribute to the reduction the plant growth (Forsum *et al.*, 2008). Our results are like those of Tonfack *et al.* (2009), who found a statistically significant impact of fertilization on tomato yield compared to the control. Our results indicate that amino-acids presented in Amino Vital and Ilsamin, are signaling molecules which may stimulate phytohormonal synthesis, leading to the nutrient translocation towards flowers (Sato *et al.*, 2006), promotion of cell division (Matsuo *et al.*, 2012) and increase of vegetative growth and fruit setting (Rouphael *et al.*, 2017). Moreover, amino-acids, sugars (Eveland and Jackson, 2012), fatty acids and lipids (Kachroo and Kachroo, 2009) may act as signaling molecules.

Total soluble solids (TSS) and fruit acids (FA) are important parameters of tomato fruit quality (Ochoa-Velasco *et al.*, 2016). TSS content in both seasons was highest in the CFBP and lowest in CFCP treatment (Table 6). The highest sugar content was observed in tomato treated with a biocontrol agent product, whilst use of pesticides lead to the lowest sugar content in fruits (Cwalina-Ambroziak and Amarowicz 2012), which agrees with our findings. In addition, biostimulator application decreased the TSS content in tomato fruits compared to the control (Grabowska *et al.*, 2015), which agrees with our observation. The same authors did not observe the alteration in fruit acids content after application of bio-stimulants. In contrast, in several researches significantly increased acidity of tomato fruits in conventional systems compared to organic was noticed (Ilić *et al.*, 2014a), whilst in others vice versa (Oliveira *et al.*, 2013). Significant variations in VC content between the seasons were detected only in CFCP and control. Alteration in L content were non-significant in this research (Table 7). In first season, significant effect of the treatments on VC content was recorded, with highest values in BP treatments, which is confirmed by other authors (Vinha *et al.*, 2014). Ertani *et al.* (2015) and Koleška *et al.* (2017) found that bio stimulants promote the synthesis of ascorbate. Using tomato cultivar

Table 6. Total soluble solids (TSS) and fruit acids (FA) in tomato fruits.

Year/ Treatment	2013	2014	Average	2013	2014	Average
	TSS (Brix)			FA (%)		
CFCP	3.95aA	3.80aA	3.87	0.22aA	0.22aA	0.220
CFBP	5.05aA	4.78aA	4.91	0.37aB	0.26aA	0.315
OFCP	4.24aA	4.50aA	4.37	0.24aA	0.25aA	0.245
OFBP	4.70aA	4.25aA	4.47	0.36aB	0.25aA	0.305
Control	4.85aA	4.45aA	4.65	0.32aAB	0.21aA	0.265
Average	4.56	4.36	-	0.30	0.24	-

Table 7. Vitamin C (VC) and lycopene (L) content in tomato fruit.

Year/ Treatment	2013	2014	Average	2013	2014	Average
	VC (%)			L (mg/100g)		
CFCP	17.00aA	28.93bA	22.97	8.90aA	6.60aA	7.75
CFBP	28.33aC	24.60aA	26.45	9.00aA	7.60aA	8.30
OFCP	25.19aBC	24.80aA	25.00	11.00bA	6.10aA	8.55
OFBP	28.33aC	24.95aA	26.64	9.60aA	6.40aA	8.00
Control	21.41aAB	37.50bB	29.50	6.80aA	7.30aA	7.05
Average	24.05	28.16	-	9.06	6.80	-

Dual, a significantly higher VC content was noticed in the control variant compared to plants treated with bio-stimulants (Grabowska *et al.*, 2015), which is like our results. The application of agrochemicals and bioproducts showed an ambiguous impact on L content without significant differences between treatments. Chemical fertilization improves the L content in tomato fruits rather than the application of bio-stimulants (Ochoa-Velasco *et al.*, 2016), which is not confirmed in our research. The same authors reported that if we exclude cultivation practices, the L content in fruits is correlated to the tomato cultivar. In Esmeralda cultivar, significant differences between bio-stimulants treated tomato and the control were not registered (Grabowska *et al.*, 2015). However, Franceska *et al.* (2020) found that bio-stimulants increased the content of carotenoids in the several tomato genotypes. These authors hypothesized that bio-stimulants application contribute to the increase of photochemical efficiency in various tomato cultivars.

It is obvious from Tables 8, 9, and 10 that seasonal variations in total N, P, K, Mg, Fe, and Zn were obtained. The highest total N content was recorded in CFBP (first season) and in control treatment (second season). Fiorentino *et al.* (2018) reported that application of bio-stimulants containing pure culture of *Trichoderma virens* GV41 improved the plant N uptake. Pelagio-Flores *et al.* (2017) reported that shifts in root architecture and increase of macro- and micronutrients absorption may be moderated by application of *Trichoderma*. The highest total N content in conventionally produced tomato was noticed compared to other treatments (Khan *et al.*, 2017). The same authors confirmed that the amount of other minerals such as P, K and Mg was significantly higher in organic systems which is not confirmed in our research. In contrast, a negligible impact of fertilization on Mg content in tomato fruits was previously reported (Polat *et al.*, 2010).

Nitrate accumulation increased in the high rainfall seasons, which is confirmed in other study (Ilić *et al.*, 2014b). The same authors found lower nitrate content in organic systems compared to conventional (Table 8), which is similar to our findings. Although tomato is classified as low nitrate-accumulating fruit (Ilić *et al.*, 2014b), it appears that reduction of N fertilizers application is required for safe human consumption.

Table 8. Total N, nitrates, and P content in tomato fruits.

Year/ Treatment	2013	2014	Average	2013	2014	Average	2013	2014	Average
	Total N (%)			nitrates (mg kg^{-1})			P (mg kg^{-1})		
CFCP	0.16aA	0.27bA	0.22	188bB	109aA	149	260.65bA	166.45aA	213.5
CFBP	0.17aA	0.34bA	0.25	95aA	153aA	124	263.13aA	183.77aA	223.5
OFCP	0.14aA	0.33bA	0.24	69aA	125aA	97.0	275.74aA	178.56aA	227.2
OFBP	0.16aA	0.23aA	0.20	92aA	150aA	121	295.84aA	179.21aA	237.5
Control	0.15aA	0.39bA	0.27	76aA	85aA	80.5	257.03aA	170.89aA	214.0
Average	0.16	0.31	-	104	124	-	270.48	175.77	-

Table 9. K and Mg content in tomato fruits.

Year/ Treatment	2013	2014	Average	2013	2014	Average
	K (mg kg^{-1})			Mg (mg kg^{-1})		
CFCP	1705.08bA	1314.34aA	1509.71	132.0bA	70.7aA	101.35
CFBP	1585.97aA	1460.79aA	1523.38	134.6bA	78.4aA	106.50
OFCP	1618.82aA	1334.60aA	1476.71	140.3bA	75.3aA	107.80
OFBP	1726.99aA	1508.26aA	1617.62	130.1aA	101.6aA	115.85
control	1519.59aA	1310.06aA	1414.82	135.2bA	95.3aA	115.25
average	1631.29	1385.61	-	134.44	84.26	-

Table 10. Fe, Zn, and Cu content in tomato fruits.

Year/ Treatment	2013	2014	Average	2013	2014	Average	2013	2014	Average
	Fe (mg kg^{-1})			Zn (mg kg^{-1})			Cu (mg kg^{-1})		
CFCP	12.35bA	2.96aA	7.66	2.90bA	1.00aA	1.95	0.86aA	0.77aA	0.81
CFBP	11.80bA	2.45aA	7.13	3.20bA	1.10aAB	2.15	1.40bC	0.70aA	1.05
OFCP	11.95bA	2.76aA	7.36	4.36bB	1.00aA	2.68	0.90aA	0.78aA	0.84
OFBP	10.92bA	3.11aA	7.02	3.00bA	1.23aBC	2.12	1.22bB	0.97aB	1.09
control	10.92bA	4.45aB	7.69	4.90bB	1.33aC	3.12	0.94aA	1.10aB	1.02
average	11.59	3.15	-	3.67	1.13	-	1.06	0.86	-

Our results did not corroborate those described previously (Tonfack *et al.*, 2009) who reported that P content in tomato fruits is highest in mineral fertilization treatments. On the other hand, using bioproducts, increases of phosphate solubilization may be achieved (Rawat and Tewari, 2011; Garcia-Lopez and Delgado, 2016). In this research, variations in P content were not statistically significant between the experimental parameters. Although P accumulation is more pronounced in OF treatments, it is evident that efficiency of bio-stimulants depends on various factors, such are climate, plant cultivar, type of application (Drobek *et al.*, 2019).

Application of fertilizers enhances the amount of K in tomato fruit (Table 9). However, there are no pronounced alterations in the K content among the treatments (Zhu and Ozores-Hampton 2017), which is confirmed in our study. The general order of accumulated minerals in tomato fruit was K>P>Mg, whilst Fe was the most abundant trace element. This statement is in accordance with other research (Erba *et al.*, 2013). High K input may result in Mg uptake deficiency (Nzanza, 2006), which is confirmed by our results.

Non-significant differences in Fe content and significant differences in Zn content between the control and experimental treatments were observed (Table 10). Our results showed higher Cu and Zn concentrations compared to previous research (Ilić *et al.*, 2014a). In contrast, when using Esmeralda F1 and Dual Plus F1 cultivars, changes in Zn content were not significant between the organic system and the control (Grabowska *et al.*, 2015). On the other hand, significant differences in Zn content of tomato fruits among the conventional and organic experimental treatments were noticed previously (Polat *et al.*, 2010). Kleiber (2014) found that cultivar modified the content of Cu and Zn in tomato fruits. Gad and Kandil (2010) suggested that Cu and Zn content in tomato fruits is influenced by adding P as nutrient, which is not confirmed in our research.

A clustergram was used for the purpose of the two-dimensional visualization of experimental data. The use of a clustergram enables the grouping of treatments and parameters.

By visual observation of the clustergram, two groups of treatments are obvious: the first group is treatments in 2013 and second in 2014 (Fig. 1). Within treatments carried out in 2013, high values of L, K, P, Fe, Mg, Zn, yield, weight, and width of fruit were detected. On the other hand, in 2014, N content was higher compared to 2013.

***Conclusions*:** Considering our results, a statistically higher yield and nitrate content (in most of the treatments) was observed in the examined treatments compared to the control, whilst K content was significantly higher in the organic fertilization and biological plant protection treatment compared to the control. Positive correlation between the nitrates, vitamin C and total N (first group), fruit acids, total soluble solids and Cu (second group), and other parameters

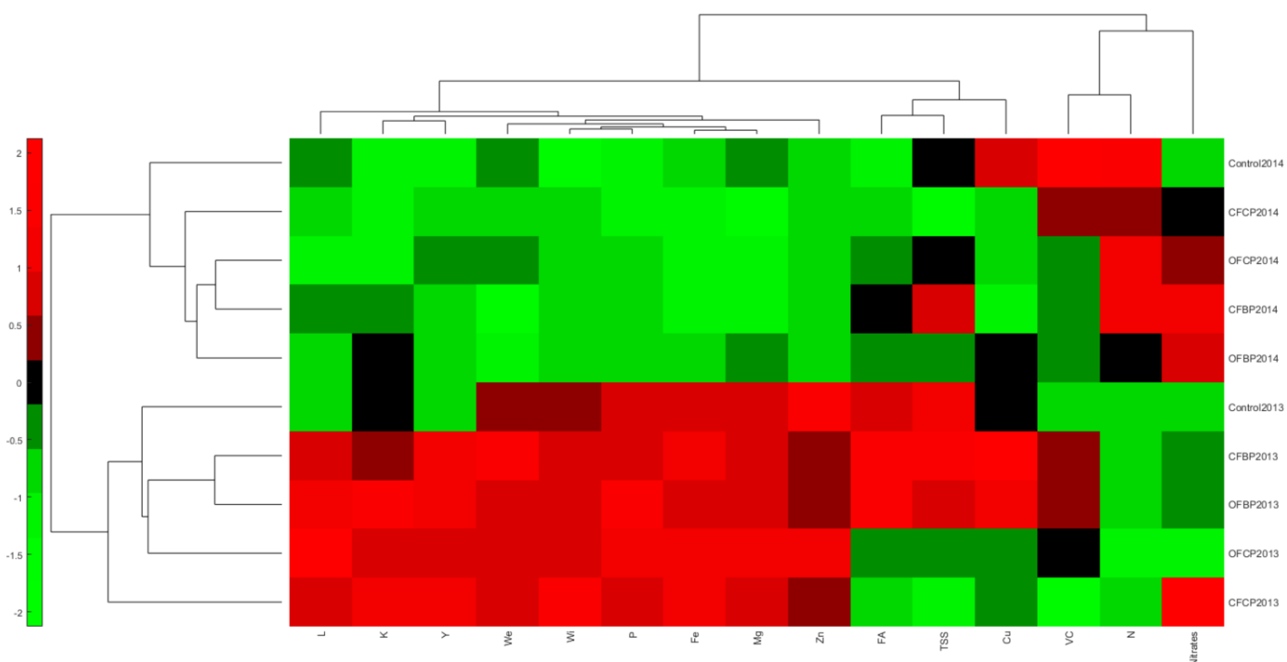

Figure 1. Clustergram which represents the grouping of treatments and observed parameters (every row represents a treatment, whilst every column represents a parameter; for labeling of variations between the parameters, different colors were used; red represents parameter values above the mean, whilst green represents values below the mean)

(third group) was observed. Application of biological plant protection led to the increase of most examined parameters in all treatments compared with chemical protection. The correlation rate is more pronounced between the parameters of the third group compared to other groups. The highest correlation rate exists between the Fe and Mg content, as well as between the P content and width of fruits. To our knowledge, this is a first report concerning the combined impact of fertilizers and plant protection products on tomatoes grown in conventional and organic systems. Certainly, there is a need for further exploration and examination of the combined effects of other fertilizers and plant protection products on tomato quality, taking into account addiotional ambiental (soil structure and depth) and quality parameters (metals, phenols and flavonoids content).

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