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The effect of nutrient concentration and inoculation of PGPR and AMF on the yield and fruit quality of hydroponic cherry tomatoes (*Lycopersicon esculentum* Mill. var. cerasiforme)

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Abstract

The purpose of this research was to study the effect of nutrient concentration and inoculation of biological agents (PGPR and AMF) in a hydroponic system of substrate culture on the growth and yield of cherry tomato plants. The greenhouse research was conducted in the Agrotechnopark of the University of Brawijaya at Jatikerto Village, Kromengan Sub-District, Malang Regency. The utilized research method was Completely Randomized Nested Design consisting of two factors. The first factor was the concentration of nutrient solution consisting of 100 % (3.5 dS m^{-1}), 75 % (2.6 dS m^{-1}), and 50 % (1.8 dS m^{-1}) concentrations. The second factor is the inoculation of biological agents consisting of no inoculation of biological agents, PGPR (Plant Growth Promoting Rhizobacteria), AMF (Arbuscular Mycorrhizal Fungi), and PGPR + AMF. The data were analyzed using an analysis of variance and continued with the test of Honest Significant Difference at 5 % level. The results showed that the interaction between the types of biological agents and nutrient concentrations significantly increased the number of flowers, number of fruits, fruit weight, fruit diameter, and sugar content of cherry tomatoes. The AMF application showed the highest fruit weight per plant and fruit diameter, especially at 100 % nutrient concentration. The AMF application also showed a higher sugar content compared to the control and PGPR but not significantly different from the PGPR + AMF treatment at all levels of given nutrient concentration. Fruit weight per plant with treatment of AMF, PGPR + AMF, and PGPR respectively produced 64.47, 48.75 and 29.39 % higher than without application of biological agents.

Key words: Bioagent, PGPR, fruits, nutrient, sugar, hydroponics, cherry tomato

Introduction

Tomato is an important vegetable and development of production technogies particularly for cherry tomato is important. However, there are many obstacles in current agricultural developments, such as unpredictable climate change (Lobell and Field, 2007; Schlenker and Lobell, 2010; McCarl *et al.*, 2016). According to Schlenker and Lobell (2010), the potential of loss in or reduction of plant production due to climate change can reach 5 %-50 %. An anticipative effort that can be taken to reduce the effect of climate change is to apply efficient and environment-friendly cultivation techniques. The hydroponic cultivation technique is one of the intensified alternatives that may be implemented to improve the quality and quantity of plant products, as well as for efficiency in the usage of land, water, and nutrients (Barbosa *et al.*, 2015; Putra and Yuliando, 2015). Hydroponics is a technique of plant cultivation without soil that utilizes the principle of providing nutrient solutions that the plant needs in a regular manner (Susila and Koerniawati, 2004).

Management of plant nutrition becomes the key factor in the success of the hydroponic cultivation technique. The conducted management effort is the regulation of concentration of nutrients. The right concentration of nutrients will increase the effectiveness and efficiency of nutrient absorption. In addition to regulation of nutrient concentration, inoculation of biological agents such as AMF (Arbuscular Mycorrhizal Fungi) and PGPR (Plant Growth Promoting Rhizobacteria) are alternative solutions to make nutrient utilization more efficient as well as to increase nutrient absorption by plants. Inoculation of AMF and PGPR provide benefits for plant growth and development. The positive effects of PGPR inoculation include its ability to provide and mobilize or facilitate the absorption of various nutrients from the soil, to synthesize and change the concentration of various growth phytohormones, and to suppress the activity of pathogens by producing various compounds or metabolites such as antibiotics and siderophores (Hayat *et al.*, 2010; Ahemad and Kibret, 2014; Nadeem *et al.*, 2017). Meanwhile, the positive effects of AMF inoculation include the production of phytohormones and secondary metabolic products such as vitamins, amino acids, and others; solubilization of minerals; increased absorption of macro- and micro-essential nutrients; increase in and efficiency of water absorption; increased plant endurance in sub-optimal environmental conditions or environmental stress such as drought, salinity, and heavy metal contamination; production of osmolytes, and improvement of soil structure (Nadeem *et al.*, 2017).

Introduction or inoculation of biological agents in hydroponic cultivation (soilless culture) is aimed to increase plant endurance toward biotic and abiotic stress, as well as to increase absorption of macro- and micro-nutrients, which affects plant growth and yield (Alsanius and Gertsson, 2004; Alsanius *et al.*, 2004; Daniel *et al*, 2006). This research was aimed to study the effect of nutrient solution concentration and inoculation of biological agents

(AMF and PGPR) in the substrate culture hydroponic system on plant growth and yield, as well as absorption of primary macro-nutrients (N, P, and K) in cherry tomato plants (*Lycopersicum esculentum* Mill. var. cerasiforme).

Materials and methods

Research site: The Agrotechnopark Greenhouse of University of Brawijaya at Jatikerto Village, Kromengan Sub-District, Malang Regency was determined as the research site. It is located at 321 m asl with an annual mean temperature of 23.9 °C, rainfall of 133.75 mm per month, and relative humidity of 81.67 %. The research was conducted from July to October, 2017. The cherry tomato seedlings used were Golden Gem variety. The seedlings were sown on the 2.5 x 2.5 cm Rockwool media. The seedlings were transplanted to polybags at 28 days after sowing (DAS), or when they had possessed, at least, 3-5 true leaves. Each polybag contained one seedling, and was added with a mixture of smooth sand planting medium, rice straw charcoal, and compost (3:1:1) (EC value of the planting medium was based on the measuring methods of PourThru Extraction EC ≈ 3.1 dS m^{-1} and Saturated Media Extraction EC ≈ 2.2 dS m^{-1}) until reaching a volume of 10,381.625 cm^3 or 71 % of the total volume of the polybag (14,534.275 cm^3). Before being filled with the planting medium, the polybags were sterilized using a 4 % formaldehyde solution with a concentration of 30 mL kg^{-1} of the planting medium. The substrate culture hydroponic system was used to cultivate the cherry tomato plants. Watering was done through drip irrigation with a mean discharge flow of 3.6 L h^{-1}. The estimated plant water necessity referred to climatology data of Karangkates Station in 2016, plant coefficient (Kc), and actual evapotranspiration (ET_0). The ET_0 equation followed the Penmann-Monteith method (Allen, 1998) and timetable of irrigation duration followed equation (Savva and Frenken, 2002). The estimation results of plant water necessity and drip irrigation duration are shown in Table 1.

Completely Randomized Nested Design consisting of two factors was used as experimental design in this research. The first factor (main plot) was three different concentrations of nutrient solution *i.e.* 100 % ≈ 3.5 dS m^{-1}, 75 % ≈ 2.6 dS m^{-1}, and 50 % ≈ 1.8 dS m^{-1}. The second factor (sub-plot) was four different inoculations of biological agents *i.e.* no inoculation/control, PGPR, AMF, and PGPR+AMF.

Hydroponics: The hydroponic nutrients was formulated following the nutritional needs of the plant. The nutritional needs of cherry tomato plants were (mg L^{-1}) : NO_3 (225); NH_4 (25); P (50); K (321); Ca (180); Mg (75); S (115); Fe (5); Mn (1); Cu (0.4); Zn (0.4); B (0.4); and Mo (0.1) (Dasgan and Ekici, 2005). Hydrobuddy 1.50 software was used to calculate the necessary chemical salts for nutrient formulation. The results of calculation informed a balanced mixture of chemical salts which was suitable for plant needs; among them were stock A mixture of 966 g calcium ammonium nitrate, 721 g potassium nitrate, and 42 g Fe EDDHA, and stock B mixture of 221 g monopotassium phosphate, 765 g magnesium sulfate, 76 g ammonium sulfate, 3 g boric acid, 3 g Zn EDTA, 8 g Mn EDTA, 3 g Cu EDTA, and 0.3 g sodium molybdate. Each 5 liters of (concentrated) nutrient stock solution which was applied as the nutrient concentration treatment was obtained by dissolving the nutrient formulation with clean water (EC ≈ 0.38 dS m^{-1}). Each nutrient stock solution was, then, diluted with water to a volume of 100 liters. Table 2 presentestimation values of electrical conductivity and requirements of each hydroponic nutrient stock solution.

Table 2. Estimation of electrical conductivity and requirements of each hydroponic nutrient stock solution

Treatments	Stock A requirement (mL 100 L^{-1})	Stock B requirement (mL 100 L^{-1})
100 % ≈ 3.5 dS m^{-1}	730	730
75 % ≈ 2.6 dS m^{-1}	540	540
50 % ≈ 1.8 dS m^{-1}	380	380

Plant growth promoting microorganism preparation: AMF and PGPR were used as biological agents in this research. The isolates of the biological agents were part of the collection of the Laboratory of Plant Diseases, Department of Plant Pests and Diseases, Faculty of Agriculture, University of Brawijaya. The formulation of utilized PGPR consisted of a mixture of several strains of non-phytopathogenic bacteria *e.g. Azotobacter chroococcum*, *Azospirillum brasilense*, *Pseudomonas flourescens*, and *Bacillus subtilis*, and the non-phytopathogenic fungus *e.g. Aspergillus niger*. The density or rate of colony-forming unit (CFU) of each bacterial isolate in the PGPR formulation was 10^8 CFU mL^{-1} (*optical density* (OD) ≈ 0.6) (Roesti *et al*, 2006). The utilized AMF was the endomycorrhizal isolate of *Glomus* sp. *Glomus* sp. is a type of endomycorrhiza included in the order Glomales, sub-order Glomineae, and family Glomaceae. The spore density of *Glomus* sp. was 5 spore g^{-1}. AMF was once inoculated during transplanting by adding 10 g of AMF granules or ± 50 spores of AMF (Tahat *et al*, 2008). AMF was placed near the roots of the plant or in the planting hole. PGPR was inoculated four times *i.e.* during transplanting, at 7, 14, and 21 DAP (days after planting) (Khaeruni *et al.*, 2013). Inoculation conducted during transplanting was performed by plunging the roots of the plant for 30 minutes. While at 7, 14, and 21 DAP,

Table 1. Plant water necessity and drip irrigation duration

Month	Date	Stage	K_C	ET_C	Plant Water Necessity	Application interval [(1)]	Duration
				(mm day^{-1})	(mL $plant^{-1}$)	(Appl. day^{-1})	(min $appl.^{-1}$)
July	29-31	Deve.	0.86	3.27	320	6[(2)]	
August	01-10	Deve.	1.04	3.99	400	7[(3)]	
August	11-20	Mid.	1.12	4.32	430	7	
August	21-31	Mid.	1.12	4.51	450	8[(4)]	
September	01-10	Mid.	1.12	4.70	470	8	1
September	11-20	Late	1.08	4.74	470	8	
September	21-30	Late	0.92	4.05	400	7	
October	01-04	Late	0.80	3.53	350	6	

[(1)] Frequency of drip irrigation application is continuous and of the same interval each day. [(2)] Interval of 4 hours application^{-1}. [(3)] Interval of 3 hours and 26 minutes application^{-1}. [(4)] Interval of 3 hours application^{-1}

it was carried out by pouring the planting medium using a suspended PGPR solution. The suspended PGPR solution had been, previously, diluted with clean water to create a suspended solution for inoculation at a concentration of 10 mL L^{-1}. A 3 cm-deep hole was initially created around the plant before performing watering (inoculation); next, the 30 mL PGPR formulation per plant (density of bacteria in suspension ≈ 10^6 CFU mL^{-1}) (Kohler *et al.*, 2008; Gul *et al.*, 2012) was given around the plant at 3 cm in distance from the plant (Amaria and Wardiana, 2014).

Data collection: The observation measured total number of flowers, total number of fruits, fruit weight and diameter, sugar content using a hand refractometer, total titrated acid using the method of NaOH titration (Tyl and Sadler, 2017), and the absorption of nutrients N, P, and K. Analysis of N-plant content utilized the Kjeldahl method (Kelley *et al.*, 1946; Cavell, 1954), while P-plant content utilized the wet digestion method, wherein the results of the plant sample destruction was measured for its content using a colorimeter (Kelley *et al.*, 1946; Cavell, 1954). The K-plant content was analyzed using the same method for P content, with the wet digestion method, and the results of the plant sample destruction was measured for its content using a flamephotometer (Cavell, 1954). Estimation of nutrient absorption was calculated based on the results of N, P, and K content analysis following the equation from (Adeli *et al.*, 2005).

Statistical analysis: Data was analyzed using combined analysis of variance (Gomez and Gomez, 1984). If the combined analysis of variance results indicated significant differences, it was further analyzed using Tukey's Honest Significance Difference (HSD) at 5 % level ($\alpha = 0.05$).

Results and discussion

Nutrient uptake: Inoculation of biological agents showed different effects on the absorption of the nutrients of nitrogen, phosphate, and potassium, while the level of nutrient concentration did not show influences (Table 3). Inoculation of PGPR, AMF, and the consortium of PGPR+AMF respectively increased nitrogen absorption by 31.02, 47.97, and 38.08 %; phosphate absorption 20.18, 68.28, and 45.80 %; and potassium absorption 27.95, 67.14 and 52.90 % compared to the control treatment. However, these results indicated the tendency for AMF inoculation to result in higher percentages of increase compared to PGPR and the consortium of PGPR+AMF (Table 3). The mechanism of the increase in nutrient absorption AMF is by root colonization using hypha/mycelium extraradicals to explore or extend its reach in the rhizosphere area, increasing the efficiency of the process of translocation of water and nutrients. Also, AMF inoculation increased the process of mineralization and solubilization of nutrients (N, P, and K) (Cardoso and Kuyper, 2006; Tanwar *et al.*, 2013). Omar (2007) reported that the improved growth could be due to direct effects of mycorrhuzal fungi on nutrient uptake and also indirect effects via mycorrhizal induced changes in the bacterial community composition.

Table 3. Effect of nutrient concentration and plant growth promoting microorganism on nutrient uptake

Treatments	Nutrient Uptake (mg $plant^{-1}$)		
	Nitrogen	Phosphorus	Potassium
Nutrient Concentration			
100 % ≈ 3.5 dS m^{-1}	198.97±74.66	24.64±10.14	268.88±100.91
75 % ≈ 2.6 dS m^{-1}	188.75±68.15	21.93±8.76	253.33±92.56
50 % ≈ 1.8 dS m^{-1}	167.80±58.39	20.14±7.37	223.78±85.08
Plant Growth Promoting Microorganisms			
Control	143.25±49.22a	16.65±5.85a	181.51±61.52a
PGPR	187.68±62.20b	20.01±6.48b	232.24±75.90b
AMF	211.96±74.65c	28.01±10.44d	303.37±87.58d
PGPR+AMF	197.79±68.25bc	24.27±8.29c	277.53±102.04c

Mean ± standard deviation. Values followed by the same letters in each column are not significantly different. (P>0.05)

Flowering and fruit yield: The level of nutrition concentration and inoculation of biological agents showed different effects on the number of flowers and fruits, as well as the weight of fruits per plant (Tables 4, 5, and 6). The nutrient concentration of 100 % (≈ 3.5 dS m^{-1}) significantly increased the number of flowers by 44.08 %-114.81 %, the number of fruits by 11.77 %-31.01 %, and the weight of fruits per plant by 23.49 %-62.49 % compared to the nutrient concentration of 75 % (≈ 2.6 dS m^{-1}) and 50 % (≈ 1.8 dS m^{-1}). This is in line with results of research of Valdez *et al.* (2002), Zulkarami *et al.* (2010), Zulkarami *et al*. (2012) who found that the increase of nutrient concentration is directly proportional to the increase in generative growth and plant yield. According to Rosadi *et al.* (2014), it was also found that the value of electrical conductivity appropriate to tomato plants is approximately 3.0-5.0 dS m^{-1}.

Inoculation of PGPR, AMF, and a consortium of PGPR+AMF respectively increased number of flowers by 44.02, 109.08, and 74.69 %, number of fruits by 15.69, 42.98, and 31.13 % and weight of fruits 29.39, 64.47, and 48.75 % compared to the control treatment. However, the results indicated that there was a tendency for AMF inoculation to result in higher growth percentages compared to PGPR and the consortium of PGPR+AMF (Tables 4, 5 and 6). This is in line with results of research (Poulton *et al.*, 2001; Poulton *et al.*, 2002; Subramanian *et al.*, 2006) that found that AMF inoculation increased the growth of plants, whether in the vegetative or generative phases, and have direct effects on tomato plant yield. AMF activity is able to induce growth and plant yield through the efficiency of absorption and translocation of nutrients and water (Subramanian, 2006; Tanwar *et al.*, 2013; Wahb-Allah *et al.*, 2014). In addition, AMF activity also increases the efficiency of the photosynthesis process and the production of phytohormones (such as IAA, IBA, and GA_3) (Aggarwal *et al.*, 2011; Abd-Allah *et al.*, 2015). Auxin (IAA, IBA) and gibberellin (GA_3) play important roles in plant growth and development; in sufficient concentrations, both of these phytohormones are able to initiate the formation of flowers and fruits, increased fruitset ratio, which directly affect plant yield (de Jong *et al.*, 2009). Based on the results of research, the number of flowers and fruits correlated positively with the number of fruits per plant; the correlation coefficients respectively are $r = 0.921$ and $r = 0.959$ (data not displayed). Each 1 unit increase in the number of flowers increases the fruit weight by 3.007 units, while a 1 unit increase in the number of fruits increases fruit weight per plant by 2.484 unit (Fig. 1).

Fruit quality: The level of nutrient concentration and inoculation of biological agents indicated different effects on sugar content and total titrated acid. Nutrient concentration is highly related to the value of electrical conductivity and the total contained nutrients (Trejo-Téllez and Gómez-Merino,

Table 4. Effect of nutrient concentration and plant growth promoting microorganism on number of flowers

Treatments	Number of flowers (flowers plant^{-1})		
	100 % ≈ 3.5 dS m^{-1}	75 % ≈ 2.6 dS m^{-1}	50 % ≈ 1.8 dS m^{-1}
Control	104.33±23.16 a C	79.00±20.42 a B	34.00±6.00 a A
PGPR	147.67±17.04 b C	97.67±17.16 a B	67.67±23.54 b A
AMF	201.33±17.10 d C	141.00±29.82 c B	105.33±26.31 c A
PGPR+AMF	175.33±13.65 c C	118.67±22.12 b B	85.67±24.01 b A

Mean ± standard deviation. Values sharing the same lowercase letter in each column and the same capital letter in each row do not differ significantly (P>0.05)

Table 5. Effect of nutrient concentration and plant growth promoting microorganism on number of fruits

Treatments	Number of fruits (fruits plant^{-1})		
	100 % ≈ 3.5 dS m^{-1}	75 % ≈ 2.6 dS m^{-1}	50 % ≈ 1.8 dS m^{-1}
Control	326.67±17.01 a B	293.67±7.09 a B	212.67±9.29a A
PGPR	371.67±19.22 b C	332.67±10.12 b B	259.33±8.50b A
AMF	431.33±10.02 c C	391.33±23.18 b B	368.33±27.59d A
PGPR+AMF	405.33±26.08 bc B	355.67±14.36 b A	331.33±19.04c A

Mean ± standard deviation. Values followed by the same lowercase letters in each column and the same capital letters in each row are not significantly different. (P>0.05)

Table 6. Effect of nutrient concentration and plant growth promoting microorganism on fruit yield

Treatments	Fruit yield (g plant^{-1})		
	100 % ≈ 3.5 dS m^{-1}	75 % ≈ 2.6 dS m^{-1}	50 % ≈ 1.8 dS m^{-1}
Control	508.70±16.95 a C	433.49±38.26 a B	272.68±23.16 a A
PGPR	673.22±11.41 b C	542.48±16.04 b B	356.23±33.71 b A
AMF	794.21±19.05 c C	651.67±28.93 c B	552.22±13.36 c A
PGPR+AMF	741.97±28.00 c C	573.47±15.74 b B	491.69±20.68 c A

Mean ± standard deviation. Values followed by the same lowercase letters in each column and the same capital letters in each row are not significantly different. (P>0.05)

2012). The nutrient concentration of 100 % had a total nutrient content that is higher compared to the 75 % and 50 % concentrations. The nutrient content in each nutrient concentration respectively were 250 mg N L^{-1}, 50 mg P L^{-1}, 321 mg K L^{-1} (100 %); 187.5 mg N L^{-1}, 37.5 mg P L^{-1}, 240.75 mg K L^{-1} (75 %); 125 mg N L^{-1}, 25 mg P L^{-1}, 160.5 mg K L^{-1} (50 %). Research results indicated that the nutrient concentration of 100 % (≈ 3.5 dS m^{-1}) significantly increased sugar content by 15.92 %-31.64 %, but reduced total titrated acid by 9.99 %-15.63 % compared to the nutrient concentrations of 75 % (≈ 2.6 dS m^{-1}) and 50 % (≈ 1.8 dS m^{-1}) (Tables 7 and 8). This is in line with research results reported by Wang *et al.* (2009), Almeselmani *et al.* (2010) and Fandi *et al.* (2010) who found that the increase in total nutrient content was able to increase sugar content, yet on the other hand reduced total titrated acid.

Nutrients have an important role in increasing the quality of tomato fruits (Carli *et al.*, 2011; Kondo and Higuchi, 2013), particularly for phosphate and potassium. The increase in sugar content was caused by high potassium amounts in the 100 % nutrient concentration (321 mg K L^{-1}). Potassium increases fruit sugar content through synthesis and storage of carbohydrates by activation of the sugar-synthase enzyme, transport and synthesis of proteins (amino acids), transport of sucrose, and neutralization of organic acids (Kumar and Kumar, 2007). Meanwhile, reduction of total titrated acid is due to high phosphate amounts in the 100 % nutrient concentration (50 mg P L^{-1}). The recommended potassium and phosphate contents in nutrient solutions for tomato plants is 200-300 mg K L^{-1} (Spensley *et al.*, 1978) or 300-400 mg K L^{-1} (Almeselmani *et al.*, 2010) and 20-40 mg P L^{-1} (Spensley *et al.*, 1978).

Inoculation of PGPR, AMF, and the consortium of PGPR+AMF respectively increased sugar content by 17.81, 29.95 and 25.19 % and total titrated acid by 0.94, 18.73 and 1.69 % compared to the control

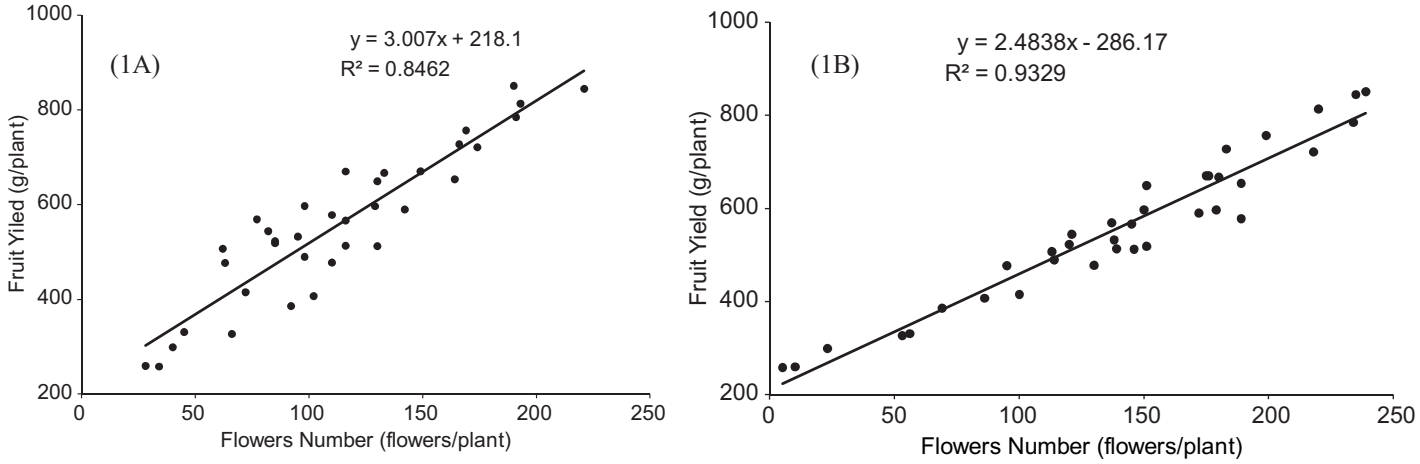

Fig. 1. Fruit yield as a function of flowers number (Y=3.007X+218.1; R^2 = 0.847) (1A) and and fruits number (Y=2.484 X-286.17; R^2 = 0.933) (1B); symbols are measurements for each nutrient concentration; lines are linear regression of fruit yield against flower number and fruit number; for AMF flower number and fruit number, respectively.

Table 7. Effect of nutrient concentration and plant growth promoting microorganism on sugar content

Treatments	Sugar Content (°brix)		
	100 % ≈ 3.5 dS m^{-1}	75 % ≈ 2.6 dS m^{-1}	50 % ≈ 1.8 dS m^{-1}
Control	6.41±0.15 a C	5.93±0.08 a B	5.20±0.14 a A
PGPR	7.83±0.42 b C	6.81±0.45 a B	6.03±0.27 b A
AMF	8.90±0.10 c C	7.37±0.32 c B	6.52±0.37 c A
PGPR+AMF	8.50±0.19 c C	7.18±0.38 bc B	6.28±0.39 bc A

Mean ± standard deviation. Values followed by the same lowercase letters in each column and the same capital letters in each row are not significantly different. (P>0.05)

Table 8. Effect of nutrient concentration and plant growth promoting microorganism on titratable acidity

Treatments	Titratable Acidity (%)		
	100 % ≈ 3.5 dS m^{-1}	75 % ≈ 2.6 dS m^{-1}	50 % ≈ 1.8 dS m^{-1}
Control	1.72±0.17 b B	2.17±0.22 c C	1.45±0.15 a A
PGPR	1.66±0.17 b A	1.70±0.17 a A	2.03±0.20 c B
AMF	2.04±0.20 c A	2.07±0.21 b A	2.23±0.22 d B
PGPR+AMF	1.49±0.15 a A	2.05±0.21 b C	1.89±0.19 b B

Mean ± standard deviation. Values followed by the same lowercase letters in each column and the same capital letters in each row are not significantly different. (P>0.05)

treatment. However, these results indicated a tendency for AMF inoculation to result in higher percentages of increase compared to PGPR and the consortium of PGPR+AMF (Tables 7 and 8). AMF inoculation increased sugar content is in line with the results of earlier research (Bona *et al.*, 2015; Bona *et al.*, 2017; Rouphael *et al.*, 2018). In addition, total titrated acid also increased due to AMF (Regvar *et al.*, 2003). Increase of fruit quality (sugar content and total titrated acid) due to AMF inoculation is affected by several factors, including the increase in photosynthate production (Rouphael *et al.*, 2018), solubilization and translocation of nutrients (P and K) (Giovanmetti *et al.*, 2012), and the concentration of the endogenous phytohormone abscisic acid (Aggarwal *et al.*, 2011; Abd-Allah *et al.*, 2015). Abscissic acid is one of the hormones that play an important role in the process of fruit development and ripening. Abscissic acid also increases the synthesis of fruit sugars (fructose and sucrose) while on the other hand reduces fruit acidity (Rolland *et al.*, 2006). In general, the increase of abscissic acid concentration reduced fruit acidity (total titrated acid) (Wang *et al.*, 2016), but in this research, the results are contradictive.

Fruit size: The level of nutrient concentration and inoculation of biological agents indicated different effects on fruit diameter (Table 9). In line with fruit quality, fruit diameter also experienced an increase due to the total nutrient content in the nutrient solution. The 100 % nutrient concentration (≈ 3.5 dS m^{-1}) significantly increased fruit diameter by 1.67 %-3.77 % compared to the nutrient concentrations of 75 % (≈ 2.6 dS m^{-1}) and 50 % (≈ 1.8 dS m^{-1}). The high content of phosphate (50 mg P L^{-1}) and potassium (321 mg K L^{-1}) in the 100 % nutrient concentration caused an increase in cell division and elongation. This is in line with research results of Kavanova (2006) and Ahmed *et al.* (2007).

Inoculation of PGPR, AMF, and the consortium of PGPR+AMF respectively increased fruit diameter by 3.44 %, 5.35 %, and 4.44 % compared to the control treatment. However, these results indicated the tendency for AMF inoculation to result in higher percentages of increase compared to PGPR and the consortium of PGPR+AMF (Table 9). The increase in fruit diameter may be

Table 9. Effect of nutrient concentration and plant growth promoting microorganism on fruit diameter

Treatments	Fruit diameter (cm)		
	100 % ≈ 3.5 dS m^{-1}	75 % ≈ 2.6 dS m^{-1}	50 % ≈ 1.8 dS m^{-1}
Control	2.73±0.00 a C	2.71±0.00 a B	2.65±0.00 a A
PGPR	2.83±0.01 b C	2.80±0.00 b B	2.74±0.00 b A
AMF	2.92±0.00 d C	2.83±0.01 b B	2.78±0.00 d A
PGPR+AMF	2.87±0.00 c C	2.82±0.00 b B	2.76±0.00 c A

Mean ± standard deviation. Values followed by the same lowercase letters in each column and the same capital letters in each row are not significantly different (P>0.05)

linked to the positive effects of AMF inoculation that stimulates production of phytohormones (such as auxin) and enzymes (such as sugar-synthase). The high activity of the *sugar-synthase* enzyme and the production of auxin induces cells through the increase of extensibility of cell walls (Nzanza *et al.*, 2012).

AMF inoculation resulted in positive effects by increasing growth, yield, quality, and nutrient absorption of cherry tomatoes. AMF inoculation increased the number of flowers by 109.80 %, number of fruits by 42.98 %, fruit weight per plant by 64.47 %, sugar content by 29.95 %, total titrated acid by 18.73 %, fruit diameter by 5.35 %, nitrogen absorption by 47.97 %, phosphate absorption by 68.28 %, and potassium absorption by 67.14 %. Usage of the 100 % nutrient concentration (EC ≈ 3.5 dS m^{-1}) may be recommended for cherry tomato cultivation, in particular for the hydroponic substrate culture system.

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