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Research Article
Effect of Water logging Duration on Growth Phases of Tomatoes (*Solanum lycopersicum* L.) Grafted on Eggplant Rootstock

Evy Latifah, Eko Widaryanto, Moch Dawam Maghfoer and Ariffin

Faculty of Agriculture, University of Brawijaya, Jl. Veteran Malang 65145, East Java, Indonesia

Abstract

Background and Objective: Small eggplants called Gelatik as an alternative substitute for tomato rootstocks are local eggplants that are widely available and can be easily obtained by conventional farmers. The main objective of this study was to examine the influence of water logging durations on various growth phases of tomatoes grafted on local eggplants. **Materials and Methods:** The experiment was conducted between February and December 2017. The design used was Randomized Block Design (RCBD) consisting of two factors and three replications. Factor I was the grafting of Cervo variety tomatoes onto different rootstocks and Factor II was the water logging pressure at different growth phases. **Results:** Gelatik rootstocks (BL) treated with B2V, B2B, B2H and B4V resulted insignificant differences in leaf area, plant height and weight of fruit from that of EG 203 line rootstock. EG 203 line (BEG) resulted in significantly higher than Gelatik (BL) rootstock in terms of proline level during fruiting phase (B2H, B4H). Biplot analysis showed the positive correlation between water logging tolerance score and the content of proline. **Conclusion:** The local eggplant rootstocks (Gelatik) which were water logged for up to 2 days did not show any significant difference from the recommended eggplants. Therefore, the EG 203 line can be planted under a substituted condition of sandy soil and rainy season condition.

Key words: Eggplants, cervo variety, fruiting phase, sandy soil, gelatik, water logging tolerance, rootstocks

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Corresponding Author: Evy Latifah, Faculty of Agriculture, University of Brawijaya, Jl. Veteran Malang 65145, East Java, Indonesia Tel: +628123384429

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), which is a seasonal fruit vegetable and belongs to Solanaceae family, is a horticultural commodity which has a high economic value and is potential to be exported. According to Outlook[1], the projection of national tomato demand between 2017-2021 ranges from 855-1053 t, while tomato production until 2016 only reached 157.1 t. Based on the data, efforts to increase the production and tolerance to biotic and a biotic pressures should be made. Tomatoes are very sensitive to flood, which is considered as an abiotic pressure[2-5]. The results of a study conducted by Bandi *et al.*[6] suggested that tomato plants which are water logged for 2 days in the vegetative phase reduce the production about 30% lower compared to tomato plants which are grown in field capacity conditions. One way to reduce the influence of water logging on tomato production is by grafting the scions of tomatoes and the rootstocks of eggplants[2]. Tomato plants that are grafted (grafted tomato) are expected to have the ability to withstand the water logging pressure.

The success of grafting depends very much on the selection of rootstocks and the splicing techniques used in the grafting process[7]. Because there are several rootstocks of grafted tomato plants which are capable of holding the water pressure, especially water logging, the effect of water logging the grafted tomatoes needs to be examined further. Bahadur *et al.*[8] also found that grafting tomatoes to the eggplant rootstocks can increase the tolerance of tomato plants to a water logging stress. The plant IC-354557 and IC 111056 lines are able to survive in submerged water for 72-96 h during the growth stage.

The World Vegetable Research Center (AVRDC)[9] has found that EG 195 and EG 203 eggplant accessions are compatible with tomatoes grafted and resistant to stress in the soil, including water logging. However, conventional farmers in Indonesia sometimes find it difficult to obtain the EG 203 strain recommended by the AVRDC. Therefore, it is necessary to study resistant local eggplants which can be compared to the recommended eggplant strains.

The purpose of this study was to determine the effect of water logging durations on various growth phases of tomatoes (*Solanum lycopersicum* L.) which are grafted on a local eggplant (Gelatik) of resistant rootstocks (*Solanum melongena*).

MATERIALS AND METHODS

Experiment site and cultivation conditions: The research was conducted in the greenhouse of Agricultural Extension College (STTP) in Wagir sub-district, Malang from February to December 2017. The greenhouse is located at an altitude of 400 masl. The plant materials in this study included using 2 types of rootstocks of eggplants (*Solanum melongena* L.), which were EG 203 line derived from AVRDC (The Word Vegetable Research) and rootstocks of a local eggplant from small eggplant variety (Gelatik or the eggplant usually consumed without cooking) grafted with scions of Cervo tomatoes.

Grafting preparation: Seeds from 2 types of eggplants were planted in the last week of March 2017 at a depth of 1.5-2.0 cm in small pots (7×9 cm^2 size) filled with sifted soil. After one week, Cervo tomato seeds were also planted in small pots. The rootstocks and scions were irrigated every day for 21 days. Eggplant seeds that were three weeks old were used as rootstocks, while two week old tomato seedlings were the scions. The cutting of the scions and rootstocks followed a 45° slope and was made on the sides of both the rootstocks and scions in suitable transplants to ensure cambium alignment and the grafting plants were inserted in plastic pockets. Plants that had been grafted were immediately put into the grafting chamber with a maximum temperature of 30°C and relative humidity ranging from 80-85%. Interception of light entering the grafting chamber was adjusted to reach no more than 25% of the total incoming sunlight. After 10-12 days in the grafting chamber for the unification process, the plants were put into polybags with a size of 27×27 cm^2 which were filled with a mixture of soil and cow manure with a ratio of 3:1. The seedlings were then placed in a greenhouse.

Research methodology: The design used was Randomized Block Design (RCBD) consisting of 2 factors and 3 replications. Factor 1 is Cervo variety tomatoes using different rootstocks:

- **BEG :** Cervo variety hybrid tomatoes using the EG 203 line as the rootstocks
- **BL :** Cervo variety hybrid tomatoes using small eggplant (Gelatik) as the rootstocks

Factor II is the water logging stress at different growth phases:

- **B0 :** Without water logging (control)
- **B2V :** Water logging for 2 days during the vegetative phase
- **B2B :** Water logging for 2 days during the flowering phase
- **B2H :** Water logging for 2 days during the fruiting phase
- **B4V :** Water logging for 4 days during the vegetative phase
- **B4B :** Water logging for 4 days during the flowering phase
- **B4H :** Water logging for 4 days during the fruiting phase

Plant growth observations: The observations included the following variables: the plant height which was measured from the base of the stem to the tip point of growth, leaf area which was measured using leaf area meter (LAM), total dry weight of the plant and dry weight of roots when the plant's age was 16 week after transplanting (WAT). The fruit weight of each plant was calculated from the weight of the first harvest to the last observation from 9-20 WAT.

Screening for submergence tolerance: In terms of the percentage of yellowing color in leaves, according to Mohanty and Ong[10], water logging tolerance scores are determined using a scale from 1-6, where 1 = 0%, no yellow leaves; 2 = 10-30%, yellow leaves; 3 = 30-50%, yellow leaves; 4 = 50-70%, yellow leaves;5 = when most leaves are yellow; and 6 = when all leaves are yellow.

Total chlorophyll content: The total chlorophyll content was measured based on a method by Henry and Grime[11], in which 0.1 g of a tomato leaf sample was crushed with a mortar and then filtered. The filtrate was then diluted with 90% alcohol to a volume of 25 mL and centrifuged at 4000 rpm for 10 min. The green liquid in the upper centrifuge tube is poured without exceeding the cuvette boundary mark. The absorbance was measured using optical density (OD) 665 and 647 nm in a spectrophotometer. The total chlorophyll content was calculated by the formula: Total chlorophyll (mg L^{-1}): 17.97 (A 647)+7.90 (A 665).

Leaf proline content: The measuring of proline content was carried out based on the method by Bates *et al.*[12]. First, the leaf tomato pieces were weighed 0.5 g, mashed with 5 mL sulfosalicylic acid 3%, stirred and centrifuged at 600 rpm for 3 min. Next, the supernatant was taken. The residue was added with 4 mL sulfosalicylic acid 3%, stirred and then centrifuged again. The supernatant obtained was then mixed with the previous supernatant. Supernatants that were obtained were then adjusted or held up to 10 mL. A 2 mL supernatant sample was added with 2 mL of ninhydrin acid and 2 mL of glacial acetic acid and then heated with the water heater to a temperature of 100°C. After 60 min, the reaction was stopped immediately by soaking it in ice. After cooling, 4 mL of toluene was added, stirred with vortex for 15 sec and allowed to sit at room temperature until the toluene phase is separated from the water phase. The toluene absorbance phase was read by spectrophotometer at a wavelength of 520 nm with toluene as blank. The amount of proline can be calculated based on standard curves (which were made with five points, respectively (0.200, 400, 600 and 800 µg mL^{-1}). Proline content is calculated based on the equation:

$$\text{Proline} = \frac{\text{Proline (µg)} \times \text{Toluene (mL)} \times \text{mL terra mL}^{-1}\text{ sample}}{\text{Sample (g)}}$$
$$= \text{µg g}^{-1}\text{ fresh weight}$$

Harvesting: Harvest started when the age of plant was ±9 week after transplant (WAT). Harvesting was conducted when the fruit had turned to a red color characteristic. It was done until the age of ±20 WAT.

Statistical analysis: The data of dry weight of root, leaves area, plant height, prolin and chlorophyll content were recorded and subjected to two-way analysis of variance (ANOVA) at the significant level p = 0.05. The data was analyzed using a variety of F-test analysis at the level of 5% to test whether or not the interaction is significant. If significance of F is less than 5%, the data is significantly different. Consequently, the data is then analyzed further using the least significant difference (LSD) test at the 5% level[13]. Simple correlation coefficients among variable were determined using mean values for rootstocks of tomato and water logging treatment. Biplots of principle components derived from values of each treatment were used to comprehensively identify tomatoes rootstocks, i.e., those that were affected by the stress water logging treatments. This was computed by use of GENSTAT software (Version 18.2).

RESULTS

Total dry weight of plant: The results showed that the treatment of water logging on the grafted tomatoes affected the total dry weight of the plants (Table 1). From the results of the variance analysis, it is seen that there was no interaction between the types of tomato rootstocks grafted or the various periods of water logging at different growth phases and the total dry weight of the plants. From each treatment of the rootstocks, there was no significant difference between the total dry weight of the plant and the type of rootstocks used but there was a significant difference among the water logging treatments given at different phases. The results of water logging treatment in different phases showed that the total dry weights of the plants treated with the 2-day water logging during the vegetative phase (B2V) and the 2nd day water logging treatment during the fruiting phase (B2H) were not significantly different from those of the control treatment (B0).

Table 1: Total dry weight of grafting tomato plants water logged in different phases at the age of 16 WAT

Treatments	Total dry weight (g/plant)
Rootstocks	
BEG (rootstocks of EG 203 line)	48.36
BL (rootstocks of Gelatik)	50.77
LSD 5%	ns
Water logging pressure at different growth phases	
B0 (control)	40.98^{d}
B2V (water logging during 2 days in the vegetative phase)	35.17^{cd}
B2B (water logging during 2 days in the flowering phase)	33.33^{bc}
B2H (water logging during 2 days in the fruiting phase)	35.33^{cd}
B4V (water logging during 4 days in the vegetative phase)	33.50^{bc}
B4B (water logging during 4 days in the flowering phase)	27.50^{ab}
B4H (water logging during 4 days in the fruiting phase)	25.50^{a}
LSD 5%	6.56
CV (%)	16.90

Means is followed by the same letter on the same column show no significant difference based on LSD test at 5% level, LSD: Least significant difference, CV: Coefficient of variance

Table 2: Dry weight root of grafted tomato plants water logged in different phases at the age of 16 WAT (week after planting) (g/plant)

Treatments	B0	B2V	B2B	B2H	B4V	B4B	B4H
BEG	1.33^{a}	1.83^{ab}	1.5^{ab}	1.75^{ab}	2^{b}	2.08^{b}	1.92^{ab}
	A	A	A	A	B	B	B
BL	1.17^{ab}	1.58^{b}	1.08^{ab}	1.33^{ab}	1^{ab}	0.92^{a}	0.83^{a}
	A	A	A	A	A	A	A
LSD 5%		0.63					
CV (%)		25.1					

The numbers followed by the same lowercase letter denote insignificant difference in the same row. The numbers followed by the same uppercase letter denote insignificant difference in the same column tested at level 5% of LSD and CV

Table 3. Leaves area of grafted tomato plants water logged in different phases at 16 WAT (Week after planting) (cm^2/plant)

Treatments	B0	B2V	B2B	B2H	B4V	B4B	B4H
BEG	986.7^{b}	880^{ab}	768^{ab}	672^{a}	928^{ab}	874^{ab}	752^{ab}
	A	A	A	A	A	B	B
BL	1643^{c}	784^{b}	688^{b}	560^{ab}	779^{b}	560^{ab}	357^{a}
	B	A	A	A	A	A	A
LSD 5%		267					
CV (%)		20					

The numbers followed by the same lowercase letter denote insignificant difference in the same row. The numbers followed by the same uppercase letter denote insignificant difference in the same column tested at level 5% of LSD and CV

Dry root weight: From the results of variance analysis shown in Table 2, it was observed that there was an interaction between the types of grafted rootstocks and the periods of water logging found in the dry weight of plant roots. In the control treatment up to 2 days of water logging (B0, B2V, B2B, B2H), the rootstocks of the EG 203 (BEG) lines and Gelatik (BL) varieties resulted in not significantly different root dry weights. However, there was a significant difference between the EG 203 line (BEG) and Gelatik (BL) rootstocks at all stages of growth after they were given water logging treatments for up to 4 days. There was an increase in the dry weight of plant roots in rootstocks of the EG 203 lines (BEG) at 4 days of water logging treatment in the vegetative phase (B4V) and flowering (B4B) compared to controls, which did not show significant differences with the water logging treatment 4 days in fruiting phases (B4H).

Leaf area: It was studied that there was an interaction between the types of grafted rootstocks and various periods of water logging at different growth phases which affected the leaf area of plants at the age of 16 WAT (weeks after treatment). From Table 3, it is shown that tomatoes with the control treatment of EG 203 line as rootstocks without water logging produced plant leave areas that were not significantly different compared to the rootstocks with water logging treatment for 2 days in phases of flowering (B2B), vegetative phase (B2V) and water logging treatment 4 days in phases of vegetative (B4V), flowering (B4B) and fruiting phases (B2H).

The tomato treatment with Gelatik rootstocks (BL) resulted in leaf area that was not significantly different compared to the EG 203 line rootstocks with the water logging treatment for 2 days during the vegetative (B2V), flowering (B2B) and fruiting (B2H) phases and rootstocks which were water logged for 4 days in the vegetative phase (B4V).

Table 4: Plant height of grafted tomato plants water logged in different phases at 16 WAT (cm/plant)

Treatments	B0	B2V	B2B	B2H	B4V	B4B	B4H
BEG	160.1c	107.2^{ab}	125^{ab}	131.2^{bc}	100^{a}	97.22^{a}	122.8^{ab}
	A	A	A	A	A	A	B
BL	157.6^{d}	117^{bc}	144.1^{cd}	149.1^{d}	126^{bc}	97.56^{ab}	86.78^{a}
	A	A	A	A	A	A	A
LSD 5%		29					
CV (%)		14					

The numbers followed by the same lowercase letter denote insignificant difference in the same row. The numbers followed by the same uppercase letter denote insignificant difference in the same column tested at level 5% of LSD and CV

Plant height: From the results of Table 4, it was found that there was an interaction between the types of grafted tomato rootstocks and various periods of water logging at different phases of growth and the plant height at the age of 16 WAT. In the control treatment, the rootstocks which were water logged for 2 days in all phases (B0, B2V, B2B, B2H) and rootstocks which were water logged for up to 4 days at the vegetative and flowering phases showed no significant difference in the plant height between the rootstocks of the EG 203 (BEG) lines compared Gelatik (BL).

Tomatoes with Gelatik rootstock (BL) without water logging (B0) did not have significantly different plant growth compared to the tomatoes whose rootstocks were water logged for 2 days during flowering (B2B) and fruiting phases (B2H). The water logged treatment for 2 days in the flowering phases (B2B) was also not different from tomatoes water logged for 2 and 4 days in the vegetative phase (B2V, B4V). This shows that Gelatik rootstocks of tomatoes (BL) in which the water logging period was added up to 4 days during the vegetative phase were still able to reach significant plant growth.

Plant tolerance scores: The level of tolerance of grafted tomato to water logging treatment is shown in Table 5. From the results of variance analysis, it was found that there was no interaction between the types of grafted tomato rootstock and various periods of water logging at different phases of growth for water logging tolerance scores. This is because the two types of rootstock used come from the eggplant and have almost the same description of the plant.

From the analysis on the effect of water logging treatment in different phases, it can be seen that water logging tolerance score was low in the water logging during 2-days in the vegetative phase (B2V) was not significantly different from the control treatment (without water logging). This research shows that water logging for 2 days in the vegetative phase indicated a high level of tolerance because it is not different from the treatment on the control plants (without water logging). Then the treatment of water logging for 2 days in the flowering phase (B2B), which was not different from the water logging treatment for 4 days in the vegetative phase (B4V). A high tolerance score shows that the tolerance to water logging decreased, which was shown in plants treated with 4-day of water logging in flowering and fruiting phase (B4B and B4H).

Table 5: Grafted tomato tolerance score when water logged in different phases

Treatments	Plant tolerance score
Rootstocks	
BEG	3.63
BL	3.25
LSD 5%	ns
Water logging pressure at different growth phases	
B0	1.00^{a}
B2V	1.60^{ab}
B2B	1.77^{bc}
B2H	2.97^{de}
B4V	2.43^{cd}
B4B	3.38^{e}
B4H	2.9d^{e}
LSD 5%	0.76
CV (%)	28.20

Means followed by the same letter on the column showed no significant difference based on LSD test at level 5%, LSD: Least significant difference, CV: Coefficient of variance. Plant tolerance score where no. 1 very resistant category (0% no yellow of color leaves), no. 2 resistant category (1-10% color of yellow leaves), no. 3 rather resistant category (11-30% color of yellow leaves), no. 4 rather sensitive category (31-60% color of yellow leaves), no. 5 sensitive category (61-80% color of yellow leaves), no. 6 very sensitive category (81-100% color of yellow leaves)

Proline: From the results of the variance analysis, it is shown that there was an interaction between the types of rootstocks and the period of water logging in different phases. Table 6 shows the effect of water logging on the proline level of grafted tomatoes. Tomatoes grafted onto EG 203 line (BEG) rootstocks treated without water logging (B0) produced a low proline level, which was not different from tomatoes grafted on to Gelatik rootstocks (BL) treated without water logging (B0). A high proline content produced by tomato with EG 203 line rootstocks (BEG) was significantly different from that produced by tomatoes grafted on to Gelatik rootstocks (BL) for the 2-day water logging treatment during the fruiting phase (B2H).

When the water logging period increased to 4 days during flowering (B4B) and fruiting (B4H) phases, the proline

Table 6: Proline level on grafted tomato leaves water logged at different phases

Treatments	B0	B2V	B2B	B2H	B4V	B4B	B4H
BEG	0.439^{a}	0.556^{b}	0.838^{de}	0.901^{e}	0.511^{ab}	0.688^{c}	0.767^{d}
	A	A	A	B	A	A	B
BL	0.415^{a}	0.521^{b}	0.8^{d}	0.862^{e}	0.474^{ab}	0.655^{c}	0.729^{cd}
	A	A	A	A	A	A	A
LSD 5%		0.079					
CV (%)		7.25					

The numbers followed by the same lowercase letter denote insignificant difference in the same row. The numbers followed by the same uppercase letter denote insignificant difference in the same column tested at level 5% of LSD and CV

Table 7: Total chlorophyll content of leaves of grafted tomatoes treated with water logging at different phases (mg g bs^{-1})

Treatments	B0	B2V	B2B	B2H	B4V	B4B	B4H
BEG	0.696^{bc}	0.647^{b}	0.559^{a}	0.727^{c}	0.655^{b}	0.727^{c}	0.654^{b}
	B	B	A	B	B	B	B
BL	0.602^{bc}	0.570^{b}	0.567^{b}	0.631^{c}	0.504^{a}	0.485^{a}	0.468^{a}
	A	A	A	A	A	A	A
LSD 5%		0.05					
CV (%)		4.46					

The numbers followed by the same lowercase letter denote insignificant difference in the same row. The numbers followed by the same uppercase letter denote insignificant difference in the same column tested at level 5% of LSD and CV

level decreased in both rootstocks of the EG 203 line (BEG) and Gelatik (BL) eggplants. Tomatoes grafted onto EG 203 line (BEG) and tomatoes grafted on to Gelatik (BL) rootstocks produced significantly different proline levels when they were water logged for 2 and 4 days during the fruiting phase (B2H, B4H).

Chlorophyll: There was an interaction between the types of rootstocks with the length of the water logged period in different phases. Table 7 shows the effect of water logging on the total chlorophyll content of grafted tomatoes. The total chlorophyll produced by the EG 203 line control group was not different from that produced by the EG 203 line with water logging treatment for 2 days in the vegetative (B2V) and the fruiting (B2H) phases. Furthermore, it also was not significantly different from the water logging treatment for 4 days in all phases. Tomatoes with Gelatik rootstocks in the control treatment produced a not different total chlorophyll content from those tomatoes given the water logging treatment for 2 days in the flowering (B2B) and fruiting (B2H) phases.

Tomato yield: It was shown that there was an effect of a interaction between the types of rootstocks and the period of water logging at different phases on the fruit weight. Figure 1 shows the effect of water logging treated to the grafted tomatoes on the fruit weight.

The fruit weight of tomatoes grafted onto Gelatik (BL) rootstocks without a water logging treatment (B0) was higher than the fruit weight of tomatoes with EG 203 line (BEG) rootstocks. Furthermore, tomatoes grafted onto EG 203 line

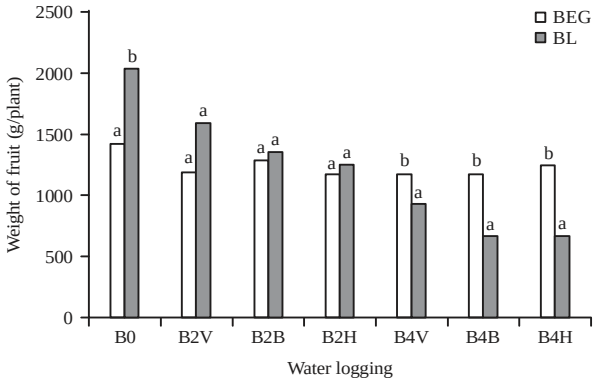

Fig. 1: Weight of grafted tomato fruit (g/plant) with two kinds of rootstock which were water logged in different phases

(BEG) rootstocks and Gelatik (BL) rootstocks treated with water logging for 2 days during the vegetative (B2V), flowering (B2B) and fruiting (B2H) phases did not show any difference in the fruit weight. When the water logging period increased to 4 days in the vegetative (B4V), flowering (B4B) and fruiting (B4H) phases, the tomatoes grafted onto 203 line (BEG) rootstocks produced a higher fruit weight compared to tomatoes grafted on to Gelatik (BL) rootstocks.

Multivariate biplot analysis: From the biplot analysis in Fig. 2, it can be concluded that the total diversity obtained is 69.66%. The measure of conformity that can be described in the biplot graph of the second dimension is 69.66%, which is quite high, so that the results of the biplot are quite

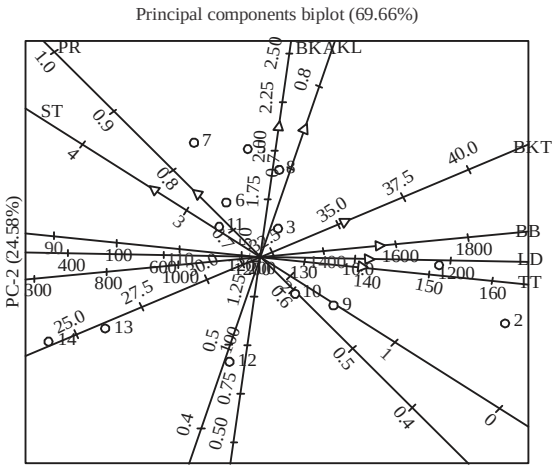

Fig. 2: Biplot main component analysis of grafting tomato plants that were water logged in different phases. Based on the resulting variable value, a positive correlation is generated in group I (upper right) consisting of BB: Fruit weight, TT: Plant height, LD: Leaf area, BKT: Total dry weight of plant, BKA: Dry root weight and KL: Chlorophyll. Correlation with variables in group II (upper left) consisting of PR: Proline and Sk: Tolerance score

representative. The Fig. 2 shows that plant's height, leaf area, plant's weight, chlorophyll, root dry weight and fruit weight are the variables which are most influenced by the types of tomato rootstocks used and the water logging treatment given in different phases. The angle formed between these variables is less than 90° showing a positively strong correlation among plant height, leaf area, plant weight, chlorophyll, root dry weight and fruit weight.

Variations of the variable in water logging tolerance scores and proline are insignificantly correlated with plant's height, leaf area and fruit weight variables. The higher the water logging tolerance score and the proline content, the lower the leaf area and plant height, while the weight of the crop fruit also decreases. Water logging tolerance scores have a high correlation with the proline content. The angle formed by these two variables is very small, less than 90°, indicating a strong correlation between water logging tolerance scores and proline. With increasing levels of wilted leaves when given water logging pressure during the fruiting phase, a high water logging tolerance score will be followed by an increase in the content of proline.

DISCUSSION

Tomato plants are difficult to grow on water logged soil. In a water logged condition, the tomato root becomes easily rotten and it is unable to absorb nutrients in the soil. Tomatoes that are grafted on the eggplant rootstocks are expected to grow better and to be more resistant to pressure. Efforts to obtain information that Gelatik can be used as an alternative to substitute of eggplant EG 203 line were observed in morphological variables (total plant dry weight, root dry weight, leaf area, plant height, plant tolerance level), physiological variables (proline and chlorophyll) and then yield fruit obtained.

The control group tomatoes (B0) grafted on to Gelatik rootstocks (BL) did not show significantly different results from tomatoes water logged for 2 days in all phases. This also showed that the tomatoes grafted on to Gelatik as rootstocks (BL) whose water logging period was added up to 4 days during the vegetative phase was still able to achieve not significantly different plant growth (leaf area, plant height). In accordance with the recommendations by Wang and Cheng[14], the use of resistant rootstocks for tomato plants is expected to help tomato plants survive in water logged soils in addition to being able to select lines that are resistant to diseases. Tolerant genotypes have stronger shoot and root growth which can hold in temporary water logging[15,16]. The results of research by Islam *et al.*[17] showed that the relative root dry weight of 56 genotypes produced new roots during the water logging recovery period, which was faster than the root development under normal conditions. According to Harti and Alfandi[18], water logging treatment is able to stimulate plant roots in nutrient absorption so that the vegetative growth of the plant can be optimized. The observation of tomatoes with EG 203 line (BEG) rootstocks water logged for 2 days in all phases did not show any difference from those with 4 days water logging. The survival of EG 203 line as a rootstocks under water logged until 4 day at all phases treatment were shows the higher root dry weight indicates an indication of aerenchyma root formation in the rootstock EG 203. Whereas the aerenchyma can increase root porosity. Existence porosity shows more gas to be present within the internal tissue of root[19]. Since that anaerobic conditions should be supported by possess higher porosity with characteristic and numerous large aerenchyma by water logged roots support for tolerance of anaerobic conditions[20].

From the results of the analysis of variance, it is found that there were no interactions between the types of grafted tomato root stems and various periods of water logging at different growth phases and water logging for tolerance scores and total dry weight. This is because the two types of rootstock used come from eggplants and have almost the same characteristics. Chlorosis and wilted leaves are major indicators of stress caused by water logging as reported by

Bhatt *et al.*[2]. When the soil where tomato plants grow becomes saturated, excess water causes diffusion of gas in the soil and reduces O_2 supply to the roots.

Sudrajat *et al.*[21] stated that the concentration of proline increases during water logging or drought. Proline holds an important role in osmotic balance and acts as protection when plants are subjected to stress. Proline content increased about 100% compared to controls produced by tomato plant leaves with EG 203 line (BEG) and Gelatik eggplant (BL) rootstocks which were water logged for 2 days during fruiting phase (B2H) and it increased about of 90% for the flowering phase (B2B). These results showed that the flowering and fruiting phases are more sensitive to the water logging stress. The production and accumulation of proline by plant's tissues during stress condition are responses to adaptation. Proline as a compatible soluble can determine the osmotic potential in the cytoplasm[22]. When the water logging period increased to 4 days, the proline level decreased ranged from 8-20% in both the rootstocks of the EG 203 line (BEG) and Gelatik (BL) on all growth phases.

Gimeno *et al.*[23] showed that when water logging becomes increasingly severe, it will limit the ability of the roots to absorb water and consequently, there will be a reduction in the root hydraulic conductance, quaternary ammonium compounds and also the proline level. This is due to the presence of water logging pressure which causes an increase in the proline level in the leaves and a decrease in the proline level in the root due to degradation of organic solutes during water logging. When this happens for a longer time, these compounds can be transported from roots to shoots, which in turn can affect the proline level in the leaves[23].

Tomatoes grafted onto EG 203 line rootstocks which were treated with water logging for 4 days in all phases produced a higher total chlorophyll compared to tomatoes grafted on to Gelatik rootstock (BL) treated with 4-day water logging in all phases. This is because tomatoes with EG 203 line rootstocks had better resistance to the water logging pressure. Tomatoes with Gelatik rootstocks in the control treatment produced a not different total chlorophyll content from those tomatoes given the water logging treatment for 2 days in all phases. The results of the study by Marchioretto *et al.*[24] showed that resistant rootstocks produced chlorophyll which is not different from plants grown at normal and water logged conditions, whereas the rootstocks which does not have resistance produces a lower chlorophyll content.

Tomatoes grafted on to Gelatik rootstock (BL) treated with 4-day all phases showed that increasing water logging significantly decreased chlorophyll content and CO_2 assimilation rate. Previous findings supported current results if water logging treatment induce reducing the total chlorophyll content eventually limiting the active photosynthesis process for the tomato yield[25].

Tomatoes grafted onto EG 203 line (BEG) rootstocks produced fruit weight in the control treatments was not significantly different from those treated with water logging for 2 and 4 days at all stages. Highest fruit weight was produced by tomatoes grafted on to Gelatik rootstocks without the water logging treatment (control plants). Tomatoes grafted onto EG 203 line rootstocks was not significantly different produced fruit weight compare tomatoes onto Gelatik rootstocks in the water logging for 2 days at all stages treatments. According to Rivard and Louws[26], the stress given to grafted tomato plants is still able to increase the yield when compared to control plants. Sanchez-Rodriguez *et al.*[27] showed that the right interaction between the scion and rootstock is able to increase N element uptake and also increase the photorespiration cycle which can produce amino acids and proteins. The yields of tomato fruits that are grafted were higher than tomatoes without grafting and under water stress conditions, which are mainly associated with increased fruit weight[28].

Water logging tolerance scores have a high correlation with the proline content. With increasing levels of wilted leaves when given water logging pressure during the fruiting phase, a high water logging tolerance score will be followed by an increase in the content of proline. Sudrajat *et al.*[21] stated that the proline concentration increases during stress conditions, such as in water logging and drought. Proline plays an important role in osmosis balance and acts as protection against environmental stress. The angle formed between plant height, leaf area, plant weight, chlorophyll, root dry weight and fruit weight is less than 90° showing a strong positive correlation reached by Gelatik and EG 203 line after given the water logging treatment. The least angle formed between leaf area and fruit weight. According to Avivi *et al.*[29], the length and width of leaves are ones of the leaf size associated with the use of solar energy. The wider the size of the leaves, the more energy enters, causing the photosynthesis process to be higher. Meanwhile, chlorophyll and root dry weight are variables that have almost the same characteristics in determining the weight of the plant.

CONCLUSION

Tomatoes with the Gelatik rootstocks that grew under normal conditions without water logging produce better fruit because they produce higher fruit weight compared to

tomatoes grafted onto EG 203 line rootstocks. Until the 2-day water logging stress at all phases, there is no significant difference. Meanwhile, in some variables, it is shown that the more sensitive growth phases to the water logging stress were the flowering and fruiting phases.

SIGNIFICANCE STATEMENT

This study found that EG 203 line was proven to be resistant of water logging but the Gelatik as a rootstock of tomato grafting was more effective because it was able to survive in water logging conditions for 2 days, so it could be used an alternative of the rootstock during rainy season in sandy soil. Moreover, because the EG 203 is a line originated from AVRDC with limited availability, conventional farmers in Indonesia could use Gelatik variety which is a local eggplant as an alternative to substitute rootstocks from tomato grafting.

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