SAJAAS

Southeast Asian Journal of Agriculture and Allied Sciences
Volume 2 Issue 1

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pp. 15-29

SAJAAS | Southeast Asian Journal of Agriculture and Allied Sciences
Bulacan Agricultural State College

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Abstract

The general objective of this study was to evaluate the effects of exogenous application of PBZ and KNO_3 in tomato subjected to different water regime. Specifically, it aimed to determine the response of tomato under different water regime as affected by application of PBZ and KNO_3, and identify the optimum concentration of the two PGRs that will give highest survival of tomato in different water regime. Waterlogging caused reduction in %survival of tomato; however no further decreased from 24hrs to 48hrs waterlogging. This trend was similar to plant height, number of leaves, leaf dry weight, stem dry weight, plant dry weight, and days to flowering. In terms of PGRs, across WR, no significant effect was observed in chlorophyll content, stem dry weight, and root dry weight. Application of PBZ at any concentration caused reduction in plant height while increased leaf dry weight and plant dry weight was observed at 250 ppm. However, PBZ at 500 ppm decreased leaf dry weight. Increased plant dry weight and earlier days to flower was achieved by KNO_3 application. Combined application of 500 ppm PBZ and 8% KNO_3 decreased the survival rate and the number of adventitious roots and caused delay in initiation of adventitious roots and induction of flower. Exogenous application of PGRs at lower concentrations (4% KNO_3 + 500 ppm PBZ) showed positive results in the growth and survival of waterlogged tomato plants however, further study focused in timing of application and combination with other PGRs is also recommended.

Keywords: *waterlogging tolerance, flooding, hypoxia, paclobutrazol*

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Introduction

Climate change may be due to natural cycles such as solar cycles, volcanic eruptions, and persistent anthropogenic changes in composition of the atmosphere and/or in land use (IPCC, 2012). One of the alterations under climate change is increasing global maximum temperature. Increase in temperature disturbs the hydrologic system. Higher temperature increases the rate of evaporation making some dry areas extremely dry while some wet areas extremely wet or change in rainfall pattern. The increasing rate of evaporation will increase the frequency of more intense rainfall resulting to more frequent occurrence of flood. Floods become more prominent around the world since 1950s. It results to loss of life, damaged to properties, deterioration of health conditions due to waterborne diseases, and impact in agriculture particularly in crop production. According to United Nations (2015), climate-related disasters are causing 14% damage and loss in agricultural sector of developing countries, including the Philippines.

The Philippines as a tropical country is one of the most typhoon-prone countries in the world experiencing at least six months of rain from 11 to 25 typhoons per year. In 2016, a super typhoons Lawin (international name "Haima") and Karen (international name: "Sarika") caused Php 10.21 B damage in agriculture mostly in crop sub-sector (99.51% or Php 10.16 B). According to PhilStar Global (2016), value of damage incurred to vegetables is at P 1.7 B wherein 60% of this damage is due to flooding (United Nations, 2015). In addition to that, 18,928 MT of vegetable produce were lost and 33,501 hectares of cultivation area were affected.

In many areas, farmers are likely to plant vegetables in the late part of third quarter or early part of fourth quarter of the year because of decreasing amount of rainfall and higher price of produced. However, typhoons occuring in this part of the year are causing more damage not just because of its strength but also larger area are planted with crops, especially vegetables which are more susceptible to flooded or waterlogged conditions.

Waterlogged condition creates hypoxic (low O_2) and anoxic (abscence of O_2) conditions as it slows down the diffusion of O_2 causing imbalance on physiological processes in plant particularly respiration. The results are decreased in root activities like water and nutrient absorption, damage to cells due to reactive oxygen species (ROS) and consequently significant yield reduction (Ashraf, 2012). However, some plants have developed several adaptive mechanisms which include the development of adventitous roots (Islam *et al*., 2010), formation of aerenchyma (Jackson, 2008), presence of hypertrophied lenticels and lastly, ability to produce antioxidants to detoxify ROS (Lambers *et al*., 2008).

Plant adaptation to stress can be enhanced through breeding and application of chemicals or plant growth regulators (PGRs). Application of chemicals or PGRs is inevitable in crop production. It can be used to hasten development of mitigation and adaptation measures to maintain or even increase productivity of different crops in the face of climate change. There are reported chemicals such as paclobutrazol (PBZ) and potassium nitrate (KNO_3) that can individually alleviate to some extent the effects of waterlogging to plants. Paclobutrazol was able to protect the plants from waterlogging stress due to increased levels of antioxidant activity which combats the negative effects of ROS (Lin *et al*., 2008). In KNO_3, potassium improves photosynthetic rate and nutrient uptake hence, higher plant growth rate (De Carvalho, 2015). On other hand, NO_3^- which is reduced to NO_2^- has been observed to increase the survival of plant by playing a role as an alternative electron acceptor, improving ATP synthesis and preventing cell super reduction under hypoxic condition (Stoimenova *et al.*, 2007).

The increasing frequency of waterlogging occurrence due to climate change will cause more damage and losses in crop productivity particularly in vegetables which are highly susceptible to waterlogged stress. Among vegetable crops, tomato is widely used as experimental plant in waterlogging studies. A lot of studies have been done to maintain crop productivity or minimize losses under waterlogged condition. These include improving waterlogging tolerance through breeding, cultural practices, and application of chemicals or plant growth regulators. Improvement of waterlogging tolerance through chemical application is faster than breeding and not crop specific, meaning can be applied to other crops; and might be more productive and profitable than cultural practices. Based on recent studies, PBZ and KNO_3 have the potential of enhancing the survival and productivity of crops under waterlogged stress. However, these chemicals are not yet tested in combination in any crops under stress particularly waterlogged stress; hence, will be evaluated in this study. This study aims to investigate waterlogging tolerance of tomato using PBZ and KNO_3 and examine plant growth response. Improved waterlogging tolerance will increase crop production by maintaining crop productivity under waterlogged stress and widening the area for cultivation. Studying plant adjustment under waterlog stress will contribute to advancement of science in this field and may open door to further elevate crop productivity under such condition.

Materials and Methods

Cultural Management of Tomato

Rosanna is the variety of tomato used in the study. It is an off-season, open-pollinated variety with moderate plant vigor and prolificacy, medium maturity and flowers 27-30 days after transplanting. Rosanna has small to medium (30-60 g/fruit) high round fruits, moderately firm, and turns red orange when ripe. This variety is a heat tolerant all-season tomato with wide adaptation. The seeds were acquired from Nueva Ecija Fruit and Vegetable Seed Center (NEFVSC) in Science City of Muñoz, Nueva Ecija.

Since the study is pot experiment, black polyethylene garden bags were used. The garden bags have four drainage holes at the bottom. The polyethylene bags with size of 25 x 15 cm (diameter x height) were planted with 5 plants per pot.

Seeds were sown in a seedling tray with 2:1 river sand and organic fertilizer. Carbaryl was applied immediately against ant attack. The seedling trays were placed under shed and transferred to greenhouse made of net 5 days after sowing (DAS) when the tomato seedlings produce true leaves.

At 10 DAS, a starter solution (1tbsp of urea gal^{-1}) was applied to seedlings. Seedlings were thinned at 12 DAS. At 14 DAS, seedlings were transferred from greenhouse to full sunlight for hardening. Seedlings were watered every other day.

At 23 DAS, five seedlings were transplanted to each polyethylene bags and placed in an open area. A mixture of 5 g of 46-0-0 and 5 g of 0-0-60 is applied per pot at 49 DAS.

Plants were protected from pests and diseases during the entire period of experiment. At seedling stage of tomato, insecticide (Cartap Hydrochloride) was sprayed against leaf miner attack. It was followed by the application of fungicide (Copper Hydroxide) at 3 days after transplanting (DAT) then after waterlogging treatment. On the other hand, in terms of weed management, spot weeding was done during the entire period of experiment.

Treatments, Experimental Design and Statistical Analysis

In this study, there were two factors: water regime and combination of PBZ and KNO_3. Treatments were arranged using Split-plot in RCBD with 3 replications per treatment. Water regime or WR (0, 24, and 48 h) was assigned as main plot while combination of KNO_3 (0, 4, 8%) and PBZ (0, 250, 500 ppm) were assigned as sub plot.

At 28–35 DAS, plants were subjected to different water regime with a depth of 3-5 cm above the soil surface. Water level was maintained throughout the treatment by monitoring the water level twice a day (06:00 and 18:00 h).

Two (2) days prior to waterlogging treatment, PGRs were applied separately by foliar application, PBZ (9:00-12:00) then KNO (13:00-17:00). Card-boards were used as a barrier to facilitate separate application of PGRs as well as to avoid contamination with other treatments.

For better control of treatment application such as timing of occurrence, duration, and severity of waterlogged treatments, this study was set-up using pot experiment in an open area. In addition, it facilitated easier collection and better evaluation of samples, and easier management of large number of treatments. The data were analyzed using analysis of variance (ANOVA) to test the significance of the results and the least significant difference (LSD) for comparison of treatments with 5% level of significance.

Results and Discussions

Percent Survival (%)

The result for percent survival of tomato at 14 DAWI is presented in Table 1. Analysis of variance showed significant differences in water regimes (WR) as well as in combined concentrations of PBZ and KNO_3 (PK) but not significant in WR:PK interaction.

In terms of water regimes, regardless of duration, waterlogging caused significant reduction in survival of tomato plants; however, there was no significant reduction from 24-hr to 48-hr with 24.59% and 16.15%, respectively. According to Apal and Hirt (2004) and Ashraf (2009), the decreased survival of plant under flooded condition is linked in increased ROS which are injurious to cellular membranes and other cellular components when the concentrations reached the point of phytotoxicity, rapidly inactivating the enzymes, damaging vital cellular organelles in plants and destroying membranes by inducing the degradation of pigments, proteins, lipids and nucleic acids which eventually results to cell death (Karuppanapandian *et al*.,2011).

Table 1

Percent (%) Survival of Tomato at 14 DAWI

TREATMENT	WATER REGIME			
	Non-waterlogged	24hrs waterlogged	48hrs waterlogged	MEAN[b]
0% KNO3 + 0 ppm PBZ	70.67	44.00	20.00	**44.89a**
0% KNO3 + 250 ppm PBZ	62.67	38.67	17.33	**39.56ab**
0% KNO3 + 500 ppm PBZ	73.33	42.67	22.67	**46.22a**
4% KNO3 + 0 ppm PBZ	65.33	20.00	16.00	**33.78abc**
4% KNO3 + 250 ppm PBZ	70.67	16.00	18.67	**35.11abc**
4% KNO3 + 500 ppm PBZ	58.67	12.00	13.33	**28.00bc**
8% KNO3 + 0 ppm PBZ	45.33	24.00	12.00	**27.11bc**
8% KNO3 + 250 ppm PBZ	54.66	10.67	14.67	**26.67bc**
8% KNO3 +500 ppm PBZ	46.67	13.33	10.67	**23.56c**
MEAN[a]	**60.89a**	**24.59b**	**16.15b**	

[a,b] Means with the same letters are not significantly different at 0.05 HSD level.

Within concentration of PGRs, highest percent survival was found in highest concentration of PBZ without KNO_3 application (0%KNO3 + 500 ppm PBZ) with 46.22% but was comparable to any PBZ concentration without KNO_3; and at 0 and 250 ppm PBZ at 4% KNO_3. However, at increasing KNO_3 concentration, it seems that highest PBZ concentration had negative effect in percent survival of tomato plants. Furthermore, there was a decreasing trend in percent survival at increasing KNO_3 concentration indicating the negative effect of high level of KNO_3 on survival of tomato at vegetative phase. This result contradicts the study of Hadad *et al.* (2016) which concludes that exogenous application of K could ameliorate the negative effects of waterlogging.

Several authors had supported the finding of the study. Studies conducted by Yiu *et al*. (2008) in Welsch onion and Lin *et al.* (2008) in sweet potato, under waterlogged condition, PBZ application significantly enhanced the antioxidant system increasing the radical scavenging activity against ROS which enhances the tolerance of plants under flooded condition.

Chlorophyll Content

The result on the number of chlorophyll content of tomato at 14 DAWI was presented in Table 2. Analysis of variance showed that there was significant difference at WR only. Highest chlorophyll content was found under non-waterlogged condition, however, comparable under 48-hr waterlogged condition.

The reduced chlorophyll content observed in 24-hr is consistent with the studies of Ashraf *et al.* (2011) and Zeng *et al.* (2020) which stated that one of the first responses of plant under waterlogging is sudden reduction in the leaf chlorophyll content then chlorosis as induced by N deficiency (Jaiswal and Srivastava, 2015; Fletcher and Arnold, 1986). Waterlogging stress reduced the production of lipid peroxidation and ethylene production in the leaves as demonstrated by Habibzadeh *et al.* (2013). Furthermore, reduced chlorophyll content and damage to cells and membrane system declined the ability of the leaves to photosynthesize (Sharma *et al.*, 2022).

Table 2

Chlorophyll Content of Tomato Leaves at 14 DAWI

TREATMENT	WATER REGIME			
	0-hr	**24-hr**	**48-hr**	**MEAN[b]**
0% KNO3 + 0 ppm PBZ	57.67	54.90	56.22	**56.26**
0% KNO3 + 250 ppm PBZ	65.01	53.62	50.55	**56.39**
0% KNO3 + 500 ppm PBZ	65.60	51.14	56.19	**57.64**
4% KNO3 + 0 ppm PBZ	59.91	63.83	64.57	**62.77**
4% KNO3 + 250 ppm PBZ	65.86	46.35	64.45	**57.89**
4% KNO3 + 500 ppm PBZ	67.62	49.65	55.13	**57.47**
8% KNO3 + 0 ppm PBZ	67.89	61.89	67.47	**65.75**
8% KNO3 + 250 ppm PBZ	69.77	52.89	64.76	**62.47**
8% KNO3 +500 ppm PBZ	71.67	70.43	54.93	**65.68**
MEAN[a]	**65.67a**	**56.08b**	**59.36ab**	

[a]Means with the same letters are not significantly different at 0.05 HSD level.

Plant Height (cm)

The results for the growth of tomato 14 DAWI were presented in Table 3. Analysis of variance at 14 DAWI had both significant effects in terms of WR and combined concentration of PGRs but had no significant effect at interaction level.

Table 3

Plant Height (cm) of Tomato Plant at 14 DAWI

TREATMENT	WATER REGIME			MEAN[b]
	0-hr	**24-hr**	**48-hr**	
0% KNO3 + 0 ppm PBZ	45.75	31.68	33.25	**36.89a**
0% KNO3 + 250 ppm PBZ	33.88	25.14	26.66	**28.56c**
0% KNO3 + 500 ppm PBZ	35.63	22.44	25.97	**28.02c**
4% KNO3 + 0 ppm PBZ	41.58	33.00	30.17	**34.92ab**
4% KNO3 + 250 ppm PBZ	39.92	26.17	27.01	**31.03bc**
4% KNO3 + 500 ppm PBZ	34.02	24.11	27.50	**28.54c**
8% KNO3 + 0 ppm PBZ	40.97	30.72	30.75	**34.15ab**
8% KNO3 + 250 ppm PBZ	37.10	26.08	26.44	**29.88bc**
8% KNO3 +500 ppm PBZ	32.23	27.78	23.29	**27.77c**
MEAN[a]	**37.90a**	**27.90b**	**27.89b**	

[a,b]Means with the same letters are not significantly different at 0.05 HSD level.

In terms of WR, there was higher difference (10 cm) between non-waterlogged and waterlogged treatments but again, 24-hr and 48-hr had similar plant height. Hence, waterlogging can cause significant reduction in height of tomato plants; however, prolonging the waterlogging duration from 24-hr to 48-hr had no further reduction in height. With regards to PGRs, there was a reduction in plant height caused by PBZ in almost all levels of KNO_3 and no significant reduction from 250 to 500 ppm PBZ. According to Fletcher and Holsta (1985), they stated that the reason for the decreased plant height by exogenous application of PBZ is that triazoles (e.g. PBZ) can affect the isoprenoid pathway, altering the levels of certain plant hormones such as inhibition of gibberellin synthesis. Also, KNO_3 cannot reverse the negative effect of PBZ in plant height, as it contradicts the study conducted by Ashraf *et al.* (2011) who stated that exogenous application of K^+ increased the growth of cotton plants (*Gossypium hirsutum* L.) under waterlogged condition.

Leaf Dry Weight per Plant (g)

The results for the leaf dry weight of tomato at 14 DAWI were shown at Table 4 which showed that significant differences were shown in all factors. Highest leaf dry weight of 3.78 g was found in non-waterlogged condition but with the help of 250 ppm PBZ without KNO_3 application. Similar result was observed at the same condition in 250 ppm PBZ with 4% KNO_3.

However, under waterlogged condition, it seems that higher concentration of PBZ (500 ppm) had negative effect in leaf dry weight of tomato. In general, application of 250 ppm PBZ can increase leaf dry weight of tomato but increasing the rate further eventually decreased leaf dry weight.

Table 4

Leaf Dry Weight of Tomato at 14 DAWI

TREATMENT	WATER REGIME			MEAN[b]
	0-hr	24-hr	48-hr	
0% KNO3 + 0 ppm PBZ	1.85defghi	1.33efghijk	0.73ijk	**1.30**
0% KNO3 + 250 ppm PBZ	3.78a	1.53defghij	1.20fghijk	**2.17**
0% KNO3 + 500 ppm PBZ	1.88defgh	0.73ijk	0.78hijk	**1.13**
4% KNO3 + 0 ppm PBZ	2.54bcd	1.47defghijk	1.20fghijk	**1.74**
4% KNO3 + 250 ppm PBZ	3.52ab	2.30cdef	1.15ghijk	**2.32**
4% KNO3 + 500 ppm PBZ	2.22cdefg	0.80hijk	0.53jk	**1.18**
8% KNO3 + 0 ppm PBZ	2.40bcde	1.13ghijk	3.10abc	**2.21**
8% KNO3 + 250 ppm PBZ	1.65defghij	1.53defghij	1.35efghijk	**1.51**
8% KNO3 +500 ppm PBZ	2.24cdefg	0.40k	0.40k	**1.01**
MEAN[a]	**2.45**	**1.25**	**1.16**	

Means with the same letters are not significantly different at 0.05 HSD level.

This finding is consistent with the study conducted by Yiu *et al.* (2008) in waterlogged Welsch onion wherein lower amount of PBZ increased leaf dry weight of onion but there was no further increased at higher rate. The increased leaf dry weight can be attributed to wider and thicker leaves with more cuticular wax as mostly observed in PBZ-treated plants (Sopher, 1998) and increased cell depth and diameter and/or increased thickness of palisade and spongy mesophyll cells (Burrows *et al.*, 1992).

Stem Dry Weight per Plant (g)

The results for the stem dry weight of tomato at 14 DAWI were presented in Table 5. In terms of WR, significant reduction in stem dry weight was observed among waterlogged plants however no further reduction from 24-hr to 48-hr waterlogging. Similar to the study conducted by Tareq *et al.* (2020) and Grichko and Glick (2001), significant reduction of stem diameter was also obtained when tomato plants was subjected to different waterlogging durations. This can be attributed to reduction in the rate of photosynthesis, a physiological process responsible for production of sugar needed for the growth and development of plants.

Table 5

Stem Dry Weight of Tomato Plants at 0 and 14 DAWI

TREATMENT	WATER REGIME			MEAN[b]
	0-hr	24-hr	48-hr	
0% KNO3 + 0 ppm PBZ	1.15	0.80	0.30	**0.75**
0% KNO3 + 250 ppm PBZ	1.32	0.63	0.60	**0.85**
0% KNO3 + 500 ppm PBZ	0.84	0.40	0.37	**0.54**
4% KNO3 + 0 ppm PBZ	1.18	0.63	0.70	**0.83**
4% KNO3 + 250 ppm PBZ	1.43	0.70	0.50	**0.88**
4% KNO3 + 500 ppm PBZ	1.23	0.40	0.30	**0.64**
8% KNO3 + 0 ppm PBZ	1.12	0.57	1.00	**0.89**
8% KNO3 + 250 ppm PBZ	0.74	0.57	0.60	**0.64**
8% KNO3 +500 ppm PBZ	1.13	0.30	0.30	**0.57**
MEAN[a]	**1.13a**	**0.56b**	**0.52b**	

[a]Means with the same letters are not significantly different at 0.05 HSD level.

In this study, PGRs had no effect in stem dry weight of tomato. However, based on other studies, PBZ and KNO_3 can increase stem dry weight of plants. In the study of Tsegaw *et al.* (2005), application of PBZ increased stem dry weight of potato. On the other hand, Ashraf *et al.* (2011) found that exogenous application of K increased stem dry weight of cotton by 41.1% under waterlogged condition.

Root Dry Weight per Plant (g)

The results on the root dry weight of tomato at 14 DAWI were presented in Table 6 where significant difference at WR level only were shown. Similar to stem dry weight, highest root dry weight was obtained from non-waterlogged plants and was comparable to plants subjected for 24-hr and 48-hr waterlogging.

Moreover, no significant reduction was observed between the two WR. With regards to chemical application, no significant difference was shown among PGRs. Significant reduction of root dry weight of waterlogged plants can be attributed to reduced root size due to impede growth and damage and decay of the existing root system (Herzog *et al.*, 2015). Further, study done by Habibzadeh *et al*. (2013) elucidated that flooding significantly decreased root dry weight as a result of oxidative stress induce by waterlogged condition.

Table 6

Root Dry Weight of Tomato Plant at 0 and 14 DAWI

TREATMENT	WATER REGIME 0-hr	24-hr	48-hr	MEAN[b]
0% KNO3 + 0 ppm PBZ	0.60	0.27	0.20	**0.36**
0% KNO3 + 250 ppm PBZ	0.70	0.20	0.30	**0.40**
0% KNO3 + 500 ppm PBZ	0.42	0.20	0.20	**0.27**
4% KNO3 + 0 ppm PBZ	0.50	0.27	0.30	**0.36**
4% KNO3 + 250 ppm PBZ	0.66	0.40	0.25	**0.44**
4% KNO3 + 500 ppm PBZ	0.64	0.30	0.20	**0.38**
8% KNO3 + 0 ppm PBZ	0.51	0.23	0.30	**0.35**
8% KNO3 + 250 ppm PBZ	0.29	0.30	0.20	**0.26**
8% KNO3 +500 ppm PBZ	0.50	0.20	0.20	**0.30**
MEAN[a]	**0.54a**	**0.26b**	**0.24b**	

[a]Means with the same letters are not significantly different at 0.05 HSD level.

Plant Dry Weight of Tomato (g)

The results on the plant dry weight of tomato at 14 DAWI were presented in Table 7. Analysis of variance showed significant differences in all factors, including WR:PK interaction. Regardless of water regimes, highest plant dry weight was found in treatments subjected to non-waterlogged condition (4.20 g) compared to treatments subjected to 24-hr and 48-hr waterlogging with 2.07 g and 1.92 g, respectively. However, there was no significant reduction observed between 24-hr and 48-hr waterlogging. The reduction in plant dry weight of waterlogged tomato can be attributed to decreased in the overall growth of plants.

Table 7

Plant Dry Weight (g) of Tomato at 0 and 14 DAWI

TREATMENT	WATER REGIME 0-hr	24-hr	48-hr	MEAN[b]
0% KNO3 + 0 ppm PBZ	3.61cdefg	2.40efghij	1.23ij	**2.41**
0% KNO3 + 250 ppm PBZ	5.80a	2.37efghij	2.10ghij	**3.42**
0% KNO3 + 500 ppm PBZ	3.14cdefgh	1.33ij	1.33ij	**1.93**
4% KNO3 + 0 ppm PBZ	4.22abcd	2.37efghij	2.20fghij	**2.93**
4% KNO3 + 250 ppm PBZ	5.61ab	3.40cdefg	1.90ghij	**3.64**
4% KNO3 + 500 ppm PBZ	4.85abc	1.50hij	1.03ij	**2.46**
8% KNO3 + 0 ppm PBZ	4.03bcde	1.93ghij	4.40abcd	**3.45**
8% KNO3 + 250 ppm PBZ	2.69defghi	2.40efghij	2.15fghij	**2.41**
8% KNO3 +500 ppm PBZ	3.88bcdef	0.90j	0.90j	**2.41**
MEAN[a]	**4.20**	**2.07**	**1.92**	

Means with the same letters are not significantly different at 0.05 HSD level.

In terms of PGRs, highest dry weight of 5.80 g was acquired with application of 250 ppm PBZ without KNO_3 under non-waterlogged condition, which was comparable to 0, 250, 500 ppm PBZ with 4% KNO_3 under the same condition. Under 24-hr, highest plant dry weight was observed in 4% KNO_3 + 250 ppm PBZ but comparable to almost all PGR treatments except to those with 500 ppm PBZ indicating the negative effect of high concentration of PBZ (500 ppm) to plant dry weight of tomato subjected to 24-hr waterlogged condition. Furthermore, this negative effect of high concentration of PBZ cannot reverse by application of KNO_3. At 48-hr waterlogged condition, almost all treatments had comparable plant dry weight.

Increased plant dry weight by application of PBZ at 250 ppm can be due to increased chlorophyll levels, enlarged chloroplasts, thicker leaf tissue, increased root to shoot ratio and elevated levels of epicuticular wax formation (Watson and Himelick, 2004) morphological changes brought by PBZ. The negative effect of high concentration of PBZ in plant dry weight of tomato subjected to waterlogged condition (24-hr) as found in this study, contradicts the result of El Said *et al.* (2017) where in waterlogged servia plants, dry weight gradually increased at increased concentration of PBZ.

Days to First Initiation of Adventitious Roots

The result for the days to first initiation of adventitious roots was presented in Table 8. Analysis of variance showed that there were significant differences in combined concentrations of chemicals (PK) and WR:PK interaction. Based on the result, there was no clear trend except that plants treated with high concentration of KNO_3 and PBZ in combination (8%KNO_3 + 500ppm PBZ) caused delay in initiation of adventitious roots in different water regimes.

According to Malik *et al.* (2001), the formation of adventitious roots potentially replacing the basal roots is considered as one of the potential morphological adaptations depicted by plants under waterlogged condition. However, rapid initiation of adventitious root is not only limited in flooded condition but also in non-flooded condition as observed in this study. Based on the result, initiation of adventitious roots under non-flooded condition was triggered by the application of 0 and 250 ppm PBZ under 4% KNO_3; 0 ppm PBZ with 8% KNO_3. According to Yu *et al.* (2001), growth of adventitious roots of ginseng was increased as higher nitrate (NO_3^-) concentration (2 mg L^{-1}). PBZ promoted adventitious root formation in olive cuttings (Salari *et al.*, 2017) where PBZ treated cuttings had a higher cutting viability, rooting percentage, number of roots per cutting, root length and root fresh and dry weights than control.

Table 8

Days to 1st Initiation of Adventitious Roots

TREATMENT	WATER REGIME			MEAN[b]
	0-hr	24-hr	48-hr	
0% KNO3 + 0 ppm PBZ	4.27def	3.00i	3.87efgh	**3.71**
0% KNO3 + 250 ppm PBZ	4.20def	4.27def	4.13def	**4.20**
0% KNO3 + 500 ppm PBZ	3.80efgh	4.07def	3.96defg	**3.94**
4% KNO3 + 0 ppm PBZ	3.27ghi	3.27ghi	4.38cdef	**3.64**
4% KNO3 + 250 ppm PBZ	3.13hi	4.33cdef	4.17def	**3.88**
4% KNO3 + 500 ppm PBZ	5.13ab	4.07def	3.80efgh	**4.33**
8% KNO3 + 0 ppm PBZ	3.67fghi	4.13def	3.60fghi	**3.80**
8% KNO3 + 250 ppm PBZ	4.67bcd	4.53bcde	4.07def	**4.42**
8% KNO3 +500 ppm PBZ	5.07abc	5.03abc	5.67a	**5.26**
MEAN[a]	**4.13**	**4.08**	**4.18**	

Means with the same letters are not significantly different at 0.05 HSD level.

Number of Adventitious Roots

The result on the number of adventitious roots was presented in Table 9. Analysis of variance showed significant differences within durations of waterlogging (WR) and combined concentration of chemicals (PK) but failed to have significant effect in WR:PK interaction.

Table 9

Number of Adventitious Roots at 7 days after Waterlogging Imposition (7 DAWI)

TREATMENT	WATER REGIME			MEAN[b]
	0-hr	**24-hr**	**48-hr**	
0% KNO3 + 0 ppm PBZ	2.13	2.93	2.47	**2.51a**
0% KNO3 + 250 ppm PBZ	1.80	2.07	2.37	**2.08abc**
0% KNO3 + 500 ppm PBZ	1.80	2.27	2.16	**2.07abc**
4% KNO3 + 0 ppm PBZ	2.47	2.27	1.70	**2.28ab**
4% KNO3 + 250 ppm PBZ	2.00	2.20	2.03	**2.08abc**
4% KNO3 + 500 ppm PBZ	1.47	2.13	1.44	**1.68cd**
8% KNO3 + 0 ppm PBZ	2.07	2.60	1.87	**2.18abc**
8% KNO3 + 250 ppm PBZ	1.67	1.80	1.64	**1.70bcd**
8% KNO3 +500 ppm PBZ	1.40	1.44	1.17	**1.34d**
MEAN[a]	**1.87b**	**2.23a**	**1.87b**	

[a,b]Means with the same letters are not significantly different at 0.05 HSD level.

In terms of water regimes, highest number of adventitious roots was found in 24-hr waterlogged period with an average of 2.23. With that, it seems that the number of adventitious roots has direct relationship with initiation as faster induction of root was found in the same duration (see Table 11). Plants exposed to 48-hr waterlogging had the lowest number of adventitious roots with 1.87 with similar result in non-waterlogged condition.

In terms of PGRs, highest number of roots was attained in control but comparable to almost all treatments except to treated with 4%KNO_3 + 500ppm PBZ and to 250 and 500 ppm PBZ under 8% KNO_3. Based on the result, application of higher concentration of PBZ (combined to either 4% and 8% KNO_3) caused negative effect by reducing the number of adventitious roots of tomato under waterlogged condition.

Days to First Flowering (DAS)

Table 10 presented the result of the days to first flowering of tomato. Analysis of variance showed that different durations of waterlogging (WR) and combined concentration of chemicals (PK) influence the days to first flowering of tomato but no significant effect in WR: PK interaction.

Table 10

Days to Flowering of Tomato (DAS)

TREATMENT	WATER REGIME			MEAN[b]
	0-hr	24-hr	48-hr	
0% KNO3 + 0 ppm PBZ	52.23	60.45	59.28	**57.32ab**
0% KNO3 + 250 ppm PBZ	54.27	60.43	58.24	**57.65a**
0% KNO3 + 500 ppm PBZ	51.17	61.10	59.64	**57.30ab**
4% KNO3 + 0 ppm PBZ	48.20	57.78	57.50	**54.49c**
4% KNO3 + 250 ppm PBZ	50.23	59.00	59.83	**56.36abc**
4% KNO3 + 500 ppm PBZ	49.13	57.60	59.44	**55.39abc**
8% KNO3 + 0 ppm PBZ	50.63	57.11	57.00	**54.92bc**
8% KNO3 + 250 ppm PBZ	51.35	58.00	58.83	**56.06abc**
8% KNO3 +500 ppm PBZ	52.60	61.50	59.84	**57.98a**
MEAN[a]	**51.09b**	**59.22a**	**58.85a**	

[a,b]Means with the same letters are not significantly different at 0.05 HSD level.

In terms of water regime, earliest flowering of tomato was seen under non-waterlogged condition with an average of 51 days whereas 24-hr and 48-hr took longer days to flower with both 59 DAS. The result was consistent from the study of Tareq *et al.* (2020) wherein earliest days to flower was obtained from non-waterlogged plants while prolonged waterlogging caused further delay in flowering of tomato.

In PGRs, treatments with 4% KNO3 without PBZ application results in earlier days of flowering with an average of 55 DAS which was comparable to treatments with KNO_3 except to 8% KNO3 with 500 ppm PBZ. However, treatments applied without KNO_3 showed late floral induction. Based on the result, earlier flowering can be attributed to the application of KNO_3 either separate or combine application but in lower concentration of PBZ (250 ppm).

According to the study of Nagao and Nishina (1993) in mango, nearly 16% of the terminals treated with 4% KNO_3 flowered by six weeks after but it was still determined by the condition of the terminal buds or the environmental conditions at the time KNO_3 was applied; however, the mode of action for KNO_3 during flower initiation is not fully understood. In terms of PBZ, study conducted by Mc Daniel (1983), stated that PBZ have not influenced flower initiation in herbaceous species.

Conclusion and Recommendation

Waterlogging caused significant reduction in growth and survival of tomato however, prolonged waterlogging duration have no significant effect. Exogenous application of PBZ and $CaNO_3$, at lower concentrations, have an ability to alleviate waterlogging stress while higher concentrations of the two chemicals can intensify the negative effects of waterlogging. Further study in the timing of application and combination of PBZ and $CaNO_3$ with other chemicals is recommended to improve waterlogging tolerance of tomato against waterlogging stress.

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