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The role of nitrophenol on delaying abscission of tomato flowers and fruits

M. Djanaguiraman*, D. Durga Devi, Arun K. Shanker, J. Annie Sheeba and U. Bangarusamy

*Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore-3 , India. *e-mail: janitnau@hotmail.com*

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Abstract

Flower and fruit abscission was studied in PKM 1 cultivar of tomato. The plants were sprayed with 2 mM nitrophenol on 60 days after transplanting [(DAT), flowering] and repeated once on 70 DAT (fruit set stage). Observations were record-ed in the flower and developing fruit from 60 DAT with an interval of 5 days upto 80 DAT. Hydrogen peroxide, superoxide radical and lipid peroxidation increased from 60 DAT to 80 DAT. Activities of superoxide dismutase (SOD), ascorbate peroxidase (APOX), peroxidase (POX), catalase (CAT), proline and polyol in-creased upto 70 DAT and thereafter decreased in both nitrophenol and control treat-ments. Nitrophenol-treated plants maintained lower hydrogen peroxide content, superoxide radical and lipid peroxidation and higher activities of SOD, APOX, POX and CAT at 70 DAT than control. The results suggest that flower and fruit abscission is associated with higher oxidative stress and antioxidant activity declines at flowering and fruit set stages. Nitrophenol can alter the oxidant and antioxidant levels, which favour increased fruit set coupled with high yield.

Key words: Oxidants, antioxidant enzyme and senescence.

Introduction

The senescence process is highly regulated involving photosynthetic decline, protein degradation, lipid peroxidation and chlorophyll degradation[1]. Lipid peroxidation induced by active oxygen species (AOS) is considered to be an important mechanism of membrane deterioration[2]. Plants have evolved non-enzymatic and enzymatic protection mechanisms that efficiently scavenge AOS and prevent damaging effects of free radicals. Antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APOX) and peroxidase (POX) are involved in the scavenging of AOS. Though lot of work has been done on production of oxidants and antioxidant activity during senescence, only little informa-tion is available on the actual role of nitrophenol on oxidative stress and antioxidants. Therefore, the objective of the present experiment was to examine variations, if any, in the oxidative stress and antioxidant activity in the tomato flowers and fruits sprayed with nitrophenol during the course of its growth, and to find out the association of oxidative stress and antioxidant activity with flower and fruit shedding.

Materials and Methods

Tomato (*Lycopersicon esculentum*, Mill.) CV. PKM 1 (120 days of life span) was planted under normal conditions during 2002-2003 in the experimental field of Tamil Nadu Agricultural University, Coimbatore, India. Recommended package of practices was followed from transplanting to maturity. Observations were made in the flowers and the developing fruits at 5 days interval starting from 60 DAT to 80 DAT. At 60, 65 and 70 DAT flowers were used for assay and during 75 and 80 DAT tiny fruits (about 3 cm) were used. The plant attained flowering and fruit set stages on 60 and 70 DAT respectively. Nitrophenol was applied at the rate of 2 mM during the above mentioned stages. Unsprayed plants served as control.

Samples for all observations were collected from six plants in different rows (n = 6). From the top, fifth lateral, flowers and fruits were used for all enzymatic and non-enzymatic analyses. Maximum plant height, leaf area and total dry matter production were arrived by adopting standard procedures. Fruit setting percentage, fruit weight and yield per plant were arrived by adopting standard procedure.

Hydrogen peroxide was estimated by forming titanium-hydro peroxide complex[3] The level of lipid peroxidation was measured in terms of TBARS con-tent[4]. Superoxide dismutase activity was estimated by recording the decrease in optical density of nitroblue tetrazolium (NBT) dye by the enzyme[2]. Superoxide anion ($\cdot O_2^-$) was measured by its capacity to reduce nitroblue tetrazolium. $\cdot O_2^-$ formation was ex-pressed as DA 540 min^{-1} g^{-1} of the sample[5]. Ascorbate peroxidase was assayed by recording the decrease in optical density due to ascorbic acid at 290 nm[6]. Peroxidase activity was assayed as increase in optical density due to the formation of tetra-guaiacol[7]. Catalase activity was assayed by estimating residual hydrogen peroxide by forming titanium-hydro peroxide complex[8]. Proline and polyol contents were quantified according to Bates et al.[9] and Lewis and Smith[10] respectively. The data were analysed for student *t* and F test for significance at 5% level according to Gomez and Gomez[11].

Results and Discussion

Results on plant height, leaf area and total dry matter production, recorded at maturity, showed that nitrophenol can increase the morphological traits in tomato. Nitrophenol acts metabolically similar to auxin, which is known to significantly influence the morphological characters[12, 13]. Growth promotion by nitrophenol can be explained as the action of phenols on IAA biosynthesis and also destruction. The classical work of Tomaszewski and Thimann[14] totally supported the present observations. Datta et al.[13] and Jain et al.[15] also reported increase in morphological

attributes by nitrophenol treatment in both agricultural and horticultural crops. Hydrogen peroxide content, superoxide radicals and lipid peroxidation increased during abscission in both treatments. Hydrogen peroxide content increased slowly upto 70 DAT (Table 2), and thereaf-ter it increased rapidly upto 80 DAT in the case of control, while in the nitrophenol, increase in H_2O_2 content was slow upto 75 DAT and thereafter increased rapidly. In both the treatments, lipid peroxidation (TBARS content) increased slowly upto 70 DAT, with a steep increase between 70-75 DAT. However at 80 DAT, TBARS and hydrogen peroxide contents were higher in control than in nitrophenol treatment. The liberation of the superoxide radical ($\cdot O_2^-$) showed a low profile activity in the initial stages, but thereafter increased rapidly. In control a sudden increase in superoxide radical production was observed on 70 DAT. However, the increase was observed on 75 DAT in nitrophenol treated plants.

The degradation of membrane lipids is achieved by the concerted activities of a variety of membraneous lipolytic enzymes. In general, these include phospholipase D, phosphatidate phosphatase and enzymes that metabolize fatty acids such as lipoxygenases and enzymes that cause alkane synthesis[16]. Nitrophenol seems to reduce the activity of lipoxygenase enzyme over control. Increase in lipoxygenase activity has been related to membrane deterioration in *Phaseolus vulgaris*[17]. Initiating the chain reaction of lipid peroxidation by forming lipid hydroperoxides and superoxide radicals, this enzyme contributes to oxidative injury in membranes. Various studies have indicated an increase in lipoxygenase activity during senescence of leaves[18], flower petals[16] and tomato fruits[19]. Lipoxygenase will be acting only on free fatty acids liberated by lipolytic acyl hydrolase activity. Thus, the product of one reaction acts as substrate for the other, acting in tandem, and causing complete deterioration of membrane lipids. ROS, produced during oxidative burst, are capable of attacking membrane proteins, causing conformational changes and making them susceptible to proteolysis. The formation of superoxide radicals was suggested to be lipoxygenase mediated. Cellular damage due to peroxidation may be avoided or reduced by utilization of lipid degradation intermediates by lipid biosynthetic enzymes and by enzymes such as superoxide dismutases, catalase and peroxidases[20]. SOD activity increased to its maximum on 70th day after planting in both the treatments and thereafter, it decreased in both the treatments (Table 3).

Nitrophenol treatment maintained slightly higher SOD activity at 60 DAT, but later, the difference was very obvious. Superoxide dismutase (SOD) catalyses the disproportion of superoxide radicals and converts them to molecular oxygen and H_2O_2. Within a cell, the superoxide dismutase (SODs) constitutes the first line of defence against ROS. O_2^- is produced at any location where an electron transport chain is present and hence, O_2 activation may occur in different compartments of the cell[21] including mitochondria, chloroplasts, microsomes, lyoxysomes, peroxisomes, apoplasts and the cytosol. A marked decline in SOD activity was observed during the senescence of carnation[22], so it may be a direct evidence to conclude that the reduced activity in control plants indicates that senescence process is in progress. The increase in the SOD activity in nitrophenol treated plants may be due to decrease in active oxygen species, which are an intrinsic part of plant senescence and inhibit the process of oxidative deterioration[23].

Ascorbate peroxidase activity showed its maximum on 70 DAT in both the treatments, and then it decreased (Table 3). At 60 and 70 DAT there was not much differ-ence in ascorbate peroxidase activity in control plants, but the reduction was very distinct after 70 DAT. The reverse was ob-served in nitrophenol treated plants. Peroxidases catalyse the dehydrogenation of structurally diversed phenolic and endiolic substrates by H_2O_2 and are thus often regarded as antioxidant enzymes, protecting cells from the destructive influence of H_2O_2 and derived oxygen species[24]. Plant peroxidases are commonly known for their capability to reduce hydrogen peroxide to water at the expense of hydrogen donors like phenols in most of the cases. Application of exogenous auxins can induce peroxidase enzyme synthesis[25] and it can be concluded that nitrophenol may also possess auxin like activity. The increase in peroxidase activity is therefore, substantiated in the present study. There is a strong evidence for the involvement of peroxidase in the catabolism of indole-3-acetic acid (IAA) in plant tissue. The reaction initially proceeds through the oxidative decarboxylation of IAA by peroxidase to form an indole-3-methyl radical, which then reacts with molecular oxygen to form an indole-3-methyl hydroperoxide intermediate. Depending on the conditions of the reaction, this intermediate can be converted to either of the two main products, methylene oxindole and indole-3-methanol, which later converted to indole-3-acetaldehyde. The absence of phenolic co-factors or the presence of hydrogen peroxide (H_2O_2) has been found to favour methylene oxindole formation, whereas, reaction in the presence of phenols favours formation of indole-3-methanol[26]. It can also be concluded that, in the presence of high phenolic compound (nitrophenol) with low H_2O_2 content in nitrophenol treated plants the formation of methylene oxindole is inhibited. This may be true as peroxidase derived products, indole-3-methanol and methylene oxindole, have been identified as degradation products of ^{14}C labelled – IAA *in vitro* [27].

Catalase activity increased upto 70 DAT in both the treatments and decreased later (Table 3). The increased activity of catalase might be due to enhanced superoxide dismutase activity[28]. The increase in catalase activity might be useful in dismuting/ disproportionating H_2O_2 that is the key product in inducing senescence. In peroxisomes, catalases have an essential role in the removal of toxic H_2O_2, which is continuously formed during photorespiration, and by the dismutation of the superoxide radicals generated in the NADH-dependent electron transport system of the peroxisomal membranes[29]. The increased activity of catalase in nitrophenol sprayed plant might be correlated with decrease in membrane degradation. H_2O_2 radicals themselves mediated the induction of catalase enzyme synthesis[30], due to the nitrophenol treatment. The content of H_2O_2 was thus lowered because of high catalase activity. Catabolism of purine during senescence was mediated by H_2O_2, and due to the enhanced catalase activity the degradation of purine may be curtailed[31]. Senescence stimulates the production of superoxide radicals, which subsequently are converted into H_2O_2 by superoxide dismutase. Therefore increased SOD activity in nitrophenol-treated plant might be the reason for enhanced synthesis/activity of catalase as evidenced from the present study. The maintenance of this enzyme at higher level prevents an increase in cytosolic H_2O_2 that can create toxic conditions in the plant cell leading to oxidative stress

Table 1. Effect of nitrophenol on growth and yield in tomato.

Treatment	Morphological attributes			Yield attributes		
	Plant height (cm)	Leaf area (cm^{-2} $plant^{-1}$)	Total dry matter production (g)	Fertility coefficient (%)	Fruit weight (g $fruit^{-1}$)	Yield $plant^{-1}$ (kg)
Control	70.87±2.2[a]	1922±20.5[a]	148.2±5.2[a]	50.04±3.5[a]	44.27±5.2[a]	1.27±0.13[a]
Nitrophenol	90.73±3.2[b]	3101±16.5[b]	174.8±7.1[b]	69.44±6.8[b]	58.74±3.8[b]	1.63±0.11[b]

Values in each column with the same superscript are not significantly different at P=0.05

Table 2. Effect of nitrophenol on oxidants and antioxidants in tomato.

Treatment	60 DAT	65 DAT	70 DAT	75 DAT	80 DAT
H_2O_2 content (µmol g^{-1})					
Control	1.30±0.11[a]	2.01±0.24[a]	2.64±0.34[a]	3.41±0.23[a]	4.72±0.24[a]
Nitrophenol	1.02±0.14[b]	1.42±0.13[b]	1.96±0.42[b]	2.35±0.41[b]	3.01±0.38[b]
Thiobarbituric acid reactive substance content (µmole g^{-1})					
Control	0.226±0.01[a]	0.257±0.02[a]	0.310±0.03[a]	0.643±0.05[a]	0.830±0.06[a]
Nitrophenol	0.183±0.02[b]	0.203±0.01[b]	0.231±0.02[b]	0.320±0.08[b]	0.501±0.07[b]
Superoxide radicals content (Δ OD 540 nm min^{-1} g^{-1})					
Control	2.51±0.23[a]	3.74±0.38[a]	6.32±0.81[a]	9.81±0.65[a]	10.30±0.82[a]
Nitrophenol	1.82±0.31[b]	2.03±0.31[b]	2.10±0.65[b]	5.16±0.94[b]	7.28±0.98[b]

Values in each column with the same superscript are not significantly different at P=0.05

Table 3. Effect of nitrophenol on antioxidant enzyme activity in tomato.

Treatment	60 DAT	65 DAT	70 DAT	75 DAT	80 DAT
Superoxide dismutase (SOD) (Units min^{-1} mg^{-1} protein)					
Control	1.53±0.07[a]	2.26±0.04[a]	3.46±0.08[a]	2.06±0.12[a]	1.47±0.12[a]
Nitrophenol	1.75±0.03[b]	2.95±0.09[b]	4.06±0.09[b]	2.95±0.09[b]	1.92±0.16[b]
Ascorbate peroxidase (APOX) (µmol ascorbate oxidized min^{-1} mg^{-1} protein)					
Control	0.298±0.01[a]	0.301±0.03[a]	0.324±0.05[a]	0.273±0.04[a]	0.254±0.04[a]
Nitrophenol	0.324±0.01[b]	0.383±0.04[b]	0.452±0.06[b]	0.392±0.03[b]	0.331±0.02[b]
Catalase (CAT) (µmole H_2O_2 reduced min^{-1} mg^{-1} protein)					
Control	2.14±0.23[a]	5.18±0.42[a]	8.74±0.37[a]	5.72±0.24[a]	3.33±0.21[a]
Nitrophenol	2.83±0.31[b]	6.14±0.35[b]	9.93±0.54[b]	6.37±0.30[b]	3.79±0.14[b]
Peroxidase (POX) (nmol tetraguaiacol formed min^{-1} mg^{-1} protein)					
Control	1.20±0.21[a]	1.58±0.24[a]	1.76±0.35[a]	1.12±0.30[a]	0.97±0.17[a]
Nitrophenol	1.72±0.15[b]	2.12±0.32[b]	2.58±0.28[b]	1.82±0.14[b]	1.50±0.13[b]

Values in each column with the same superscript are not significantly different at P=0.05

Table 4. Effect of nitrophenol on proline and polyol content in tomato.

Treatment	60 DAT	65 DAT	70 DAT	75 DAT	80 DAT
Proline (µg g^{-1})					
Control	430.6±10.2[a]	483.5±21.1[a]	571.6±25.9[a]	460.9±62.3[a]	428.8±24.9[a]
Nitrophenol	504.3±28.9[b]	547.8±36.7[b]	707.5±23.4[b]	686.2±38.6[b]	653.9±48.6[b]
Polyol (µg g^{-1})					
Control	383.1±11.2[a]	419.3±23.4[a]	531.7±18.9[a]	636.7±30.9[a]	437.0±15.2[a]
Nitrophenol	418.3±12.3[b]	453.2±16.2[b]	699.5±35.8[b]	831.3±48.6[b]	532.9±51.3[b]

Values in each column with the same superscript are not significantly different at P=0.05

and cell death[21, 32]. Peroxidase activity was more in nitrophenol treated tomato plants as compared with control, and at last stage of sampling (80 DAT), the increase in the enzyme activity by this treatment was 54.6 per cent over control.

Proline and polyol contents were maximum at 70 and 75 DAT respectively in both the treatments (Table 4). The data revealed that nitrophenol treatment can increase proline and polyol contents compared to control. The possible positive roles of proline under oxidative stress like senescence have been proposed with greater or lesser convictions, which include stabilization of proteins, regulation of the cytosolic pH and regulation of NAD/NADH ratio by singlet-oxygen quencher and scavenger of OH^- radicals[33]. Smirnoff and Cumbes[34] reported that proline reacts with OH^- under hydrogen abstraction by forming the most stable radical. The enhanced content of proline in nitrophenol-treated plants may function as a singlet-oxygen quencher that trap OH^- radicals and stabilizes proteins endogenously as suggested by Matysik et al.[33]. Polyols are the sugar alcohols present in plants. Ahmad et al.[35] reported the accumulation of high levels of polyhydric alcohol, sorbitol under stress conditions and found it to be a compatible cytoplasmic solute as noticed in the present study. Due to nitrophenol spray, the plants accumulated higher amount of polyol content. These compounds have been generally proposed to act as compatible solutes and used for free radical scavenging and metabolic detoxification [36].

Nitrophenol treatment increased the fruit set percentage (Table 1) by 38.7 per cent, fruit weight by 32.7 per cent and by 28 per cent over untreated control plants. The application of

nitrophenol increased fertility co-efficient and fruit weight, which are the most important yield determining components in tomato. This was also confirmed by other authors [15, 37, 38].

Conclusions

During 60-70 DAT, nitrophenol-treated plants showed rela-tively more antioxidant activity (SOD, APOX, POX and CAT) and lower hydrogen peroxide content, superoxide radical production and lipid peroxidation, while towards 80 DAT, it showed slightly lower SOD, APOX, POX and CAT activity, higher hydrogen peroxide and TBARS contents than control. These results suggest that comparatively lower antioxidant activity and increased oxidative stress (H_2O_2, superoxide radicals and TBARS contents) towards fruit set stage in control might have resulted in less fruit set percentage coupled with low yield.

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