

Research Article

Transcriptome analysis of tobacco in response to *Ralstonia solanacearum* infection

Cobra Moslemkhani¹, Javad Mozafari^{2*}, Masoud Shams-Bakhsh³ and Ebrahim Mohammadi Goltapeh³

1. Seed and Plant Certification and Registration Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran.
2. Seed and Plant Improvement Institute, Agricultural Research, Education and Extension Organization (AREEO), Karaj, Iran.
3. Department of Plant Pathology, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran.

Abstract: One of the best strategies to control bacterial wilt caused by *Ralstonia solanacearum* (Smith) is generally based on breeding resistant cultivars. The information obtained from the expression of plant defense genes will provide new insight for improving plant resistance against pathogens. This study was to identify inducible genes under defense no death (DND) reaction of tobacco (*Nicotiana tabacum*)-*R. solanacearum* interaction using cDNA-AFLP technique. In this assay five different primer combinations were used. Out of 1320 Transcript derived fragments (TDF) that were detected, 101 fragments were identified as differentially expressed genes in 0, 24, 48 and 72 hours post inoculation. Most of the differentially expressed genes were obtained 48 hours post inoculation. Following sequencing, most of sequenced TDFs showed homology to known genes interfering in signaling, regulation and defense functions. DND phenotype in tobacco has some similarities specially in signaling process with mechanism associated with induction of the hypersensitive reaction and it is distinct from general defense mechanisms.

Keyword: Tobacco, *Ralstonia solanacearum*, transcriptome, interaction

Introduction

The phytopathogenic bacterium *Ralstonia solanacearum* is a devastating, soil-borne pathogen that causes lethal wilting of plants in over 200 species (Hayward, 1991; Buddenhagen and Kelman, 1964). The strategy to control bacterial wilt is generally, based on breeding resistant cultivars, while other preventive methods are difficult to apply (Carputo and Barone, 2005).

During plant-pathogen interactions gene expressions are altered and defense mechanisms activated or suppressed. When Plants are exposed to pathogens attack, compatible interaction occurs via colonizing susceptible plant with pathogen and under incompatible interaction defense mechanisms stimulate and prevent pathogen entry, establishment and growth in the plant (Kamoun, 2001; Thordal-Christensen, 2003; Daurelio *et al.*, 2009 a, b).

Elicitation of hypersensitive reaction (HR) as incompatible reaction occurs by leaf infiltration with rich bacterial suspension and rapid necrosis of plant cells in infection site has been observed 12-24 hours post inoculation (Carney *et al.*, 1990; Klement, 1982). In compatible interaction, bacteria multiply for a prolonged period and

Handling Editor: Naser Safaie

* **Corresponding author**, e-mail: j.mozafari@yahoo.com
Received: 25 May 2016, Accepted: 9 November 2016
Published online: 1 January 2017

water soaked lesions appear nearly 3 days after inoculation (Lozano and Sequeira, 1970). Race 3 of *R. solanacearum* isolates induce defense no death reaction but don't induce HR on tobacco (OEPP/EPPO, 1990). The bacteria unable to spread into adjacent tissues and cause chlorotic reaction. The factors responsible for this resistance may be different from HR (Lozano and Sequeira, 1970). Race 3 of *R. solanacearum* isolates is the prevalent race in potato production sites in Iran (Nouri *et al.*, 2009). The level of resistance in cultivated potato varieties is low and crossing of Solanum species is time-consuming and hard, therefore the development of resistant genotypes has become a challenge for potato breeders (Carputo *et al.*, 2009).

Generally, investigation on tobacco molecular responses against *R. solanacearum* may be assisted by transferring desirable defense genes to *S. tuberosum* cultivars using genetic engineering methods.

Defense mechanisms and induced responses in the various host and non host/*R. solanacearum* interactions have been studied previously (Dahal *et al.*, 2009; Schacht *et al.*, 2011; Kiba *et al.*, 2007; Godiard *et al.*, 1990; Gao *et al.*, 2009; Esposito *et al.*, 2008).

Natural invasion of *R. solanacearum* occurs through the root system and after heavy colonization of the vascular tissues, wilting symptoms appear (Vasse *et al.*, 1995). Leaf infiltration technique, is more accurate in comparison to root inoculation and has been suggested for studying molecular aspects of Tobacco/*R. solanacearum* interactions (Kiba *et al.*, 2007)

Transcriptome analysis of incompatible response (non-host or avirulent) in tobacco and *R. solanacearum* (race 3) interaction will provide new insights for improving plant resistance against pathogens and for effective control of bacterial wilt disease. Information on the defense mechanisms and genes involved in plant-pathogen interactions would be highly desirable and necessary. This study is conducted to identify inducible genes in interaction of tobacco against *R. solanacearum* by leaf-infiltration using cDNA-AFLP method.

Materials and Methods

Plant material and bacterial inoculation procedure

Nicotiana tabacum cv. Samsun (Seed obtained from Seed and Plant Improvement Institute, Iran), were grown in pots containing a mixture of vermiculite-peat moss (3:1) under controlled greenhouse conditions at 25 °C and 10000 lux with a photoperiod of 16h. Forty days old tobacco plants were used for leaf infiltration. The bacterial strain (SH₁₂) used in this study was *R. solanacearum* race3/biovar2 isolated from potato in Khuzestan province. Culture of bacteria were routinely grown (24h, 28 °C) on yeast peptone glucose agar (YPGA) medium. Bacterial suspension of 10⁸ CFU/ml (0.1 at OD₆₀₀) from overnight bacterial culture was pressure infiltrated into the abaxial side of the leaves using a syringe without needle. Inoculated regions were harvested at 0, 24, 48 and 72 hours post inoculation (hpi). Water infiltrated leaves were used as control at the first point time. Collected tissues were frozen in liquid nitrogen immediately after harvesting. Samples were prepared in four replicates.

RNA isolation and cDNA synthesis

Total RNA was extracted from infected and non-infected tobacco using RNeasy® mini kit (Qiagen), according to the manufacturer's protocol. The mRNA was purified from 200µg of total RNA using oligotex mRNA purification kit according to the manufacturer's instructions (Qiagen). The quantity and quality of total RNA and mRNA were examined on 1% agarose gel. First strand cDNA was synthesized using first strand cDNA synthesis kit according to the manufacturer's protocol (Fermentas).

Double stranded cDNA was synthesized by adding, 20 µl first-strand cDNA reaction to a master mix consisting of 7.5 µl of 10× cDNAII buffer, 25 U of DNA Polymerase I (Promega), 2.25 U of RNase H (Promega), and 1.25 µl dNTPs (10 mM) in a final volume of 80 µl, and incubating for 2h at 16 °C. The quality of double-stranded cDNA was determined by

electrophoresis on a 1% agarose gel. The remaining sample was purified by extraction with phenol/chloroform/isoamyl alcohol (1:1:24) and then ethanol precipitated.

cDNA-AFLP analysis

A cDNA-AFLP analysis was performed as described by Bachem *et al.* (1998). Transcript derived fragment (TDFs) were obtained after digestion of the dsDNA with 5U of *MseI* and *EcoRI* (Invitrogen). *EcoRI* and *MseI* adaptors were then ligated to the digested cDNA. Ten μL of the ligation mix and *MseI* and *EcoRI* primers without selective nucleotide were used for pre-selective amplification. In pre-amplification assay, PCR conditions in volume of 25 μL were as follows: 3 μL template cDNA (ligation product), 0.2 mM dNTP (10 mM), 1x PCR buffer, 1.5 mM MgCl_2 , 1 U *Taq* polymerase and 0.4 μM of each primer (*Mse0* and *Eco0*). The temperature profile for PCR amplification was 94 °C pre-denaturation for 3 min followed by 15 cycles of denaturation at 94 °C for 30 s, annealing at 56 °C for 1 min and extension at 72 °C for 1 min, and final extension at 72 °C for 5 min. After pre-amplification the mixture was diluted 50 fold and 3 μL was used for selective amplification with 5 primer combinations (*MseAT/EcoCT*, *MseAT/EcoAC*, *MseCC/EcoCT*, *MseCC/EcoAC*, *MseAC/EcoAC*). PCR conditions were the same as pre-amplification assay. Touchdown PCR conditions for selective amplification were as follows: 94 °C pre-denaturation for 1 min followed by denaturation at 94 °C for 30 s, annealing at 65 °C for 30 s and extension at 72 °C for 30 s. (12 cycles, scale down of 0.7 °C per cycle), 30 s denaturation at 94 °C, 30 s annealing at 56 °C, 60 s extension at 72 °C (23 cycle) and final extension at 72 °C for 5 min. Selective amplification products were resolved on a 6% denaturing polyacrylamide gel (Sequi-Gen GT sequencing cell of Bio-Rad) and running for 2.5h at 105 W and 50 °C. Polyacrylamide gel was visualized by silver staining (Bassam *et al.*, 1991). TDFs of interest were excised from the gel. Each gel slice was immersed in 50 μL of

sterile water and incubated overnight at 4 °C in order to allow the DNA fragments to diffuse. After centrifugation, the extracts were reamplified using AFLP selective primers under the same PCR conditions. PCR product was purified by Fermentas DNA extraction kit according to the manufacturer's protocol then purified PCR products were sequenced. The nucleotide sequences were analyzed for homology against in Gen-Bank non-redundant database using Basic Local Alignment Search Tool (Blast) Program. Sequences were manually assigned to functional categories based on the analysis of scientific literature.

Result

Tobacco leaf reaction following bacterial infiltration

Isolate SH₁₂ induced severe chlorosis in the infiltrated area 48 h after infiltration (Table 1). The degree of chlorosis increased up to 72 h post inoculation but size of the lesion remained constant.

Table 1 Difference between true hypersensitive reaction (HR) induced by *Erwinia amylovora* and defense no death (DND) induced by *Ralstonia solanacearum*.

Symptoms	HR	DND
Restricted pathogen growth	+	+
Spot color	brown	yellow
Appearance discoloration	24 hpi	48 hpi

hpi: hours post inoculation.

cDNA-AFLP analysis

The cDNA-AFLP strategy was successfully used to characterize differential gene expression under tobacco incompatible reaction against race 3 of *R. solanacearum* infiltration. The leaves were evaluated at different times after infection including 0, 24, 48 and 72 hour post inoculation (hpi). For five primer combinations, 1320 TDFs were visualized as bands, 50-800 bp in size. To determine reproducibility of these profiles, the experiments were repeated twice (Fig. 1).

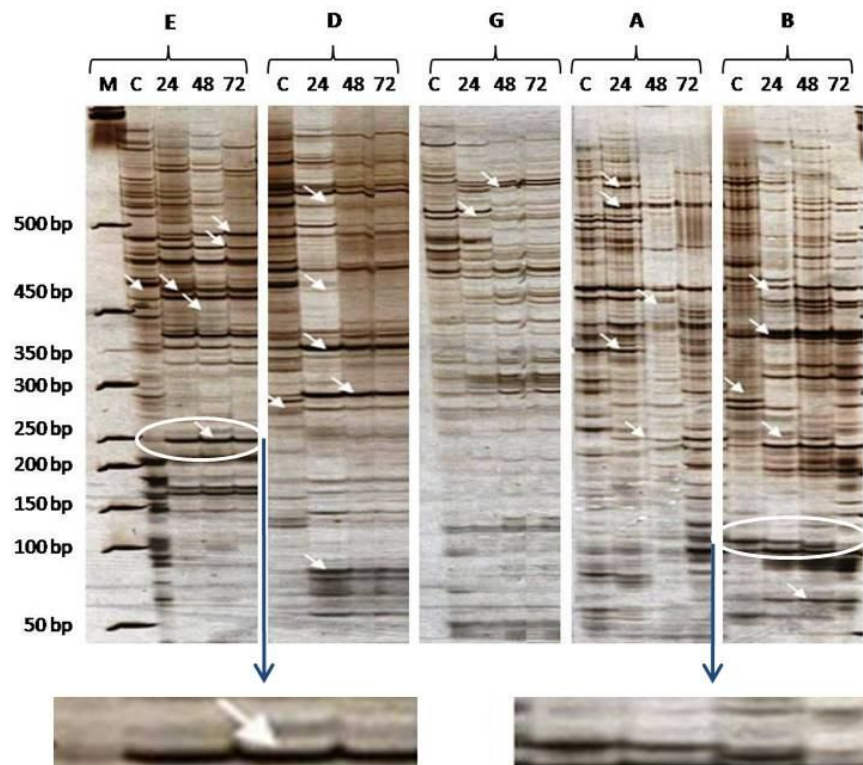


Figure 1 cDNA-AFLP display using five primers combination (E, D, G, A and B) from water infiltrated leaves (lane c), pathogen infiltrated leaves that harvested at 24, 48 and 72 hours post inoculation (hpi). Arrows represent differential bands and magnifications show different expression patterns in control sample compared to pathogen infiltrated leaves.

From 1320 TDFs, 101 genes showed significantly different expression pattern in response to bacteria infiltration. Twenty four hours after infiltration many polymorphic fragments could be evidenced and most of them were up-regulated compared to control plant. 19.2% of cDNA-AFLP fragments corresponded to up regulated transcripts and 9.3% to down regulated transcripts (Fig. 2). Twenty of these cDNA fragments were excised from the gel and sequences were determined. The recovery from acrylamide gel and re-amplification was tricky step and thus we were not able to get a clean sequence for all cDNA fragments. Out of 20 sequences we obtained 11 clean sequences from stress responsive transcripts that showed a length between 79-159 bp (Table 2).

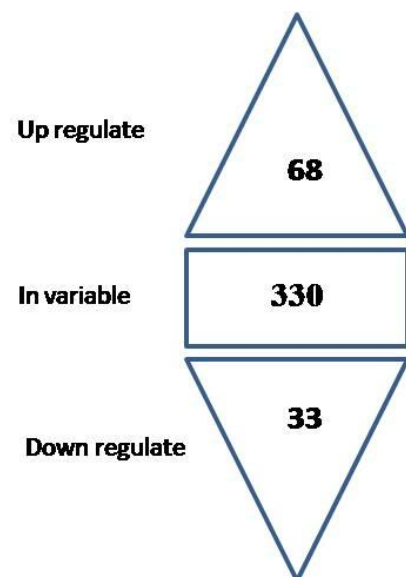


Figure 2 Overall results of cDNA-AFLP analysis in tobacco-*Ralstonia solanacearum*.

Table 2 Functional annotation of transcript derived fragments (TDFs) obtained by cDNA-AFLP in tobacco-*Ralstonia solanacearum* interaction.

TDF	Length (bp)	Annotation	E-value
TE1	154	Hypothetical protein	6e-49
TE2	138	Ascorbate peroxidase	1e-27
TE3	101	Radical induced cell death1 (RCD1)-like cell differentiation protein	8e-40
TE4	127	Plastid lipid associated protein	6e-54
TE5	159	Predicted protein Wax2 like	8e-35
TE6	154	Metal-dependent protein hydrolase	9e-50
TE8	159	Sesquiterpene synthase 1	3e-62
TE9	79	GEM-like protein 4	7e-17
TF10	117	Avr9/cf-9 rapidly elicited protein 140	6e-50
TF11	115	ABA response elements	3e-41
TF13	105	putative ML domain protein	6e-43

Bioinformatics' analyses were performed and TDFs classified in two groups with functional annotation and unknown function. The major function of deregulated genes was signaling, regulation and defense.

Discussion

Restriction of pathogen to its site of penetration is one of the plant defense strategies against pathogen. Defense No Death (DND) phenotype is induced in tobacco by race 3 of *Ralstonia solanacearum* (OEEP/EPPO, 2004). A cDNA-AFLP approach was used to study transcriptome variation during *R. solanacearum*-tobacco interaction. This revealed the presence of metabolites generally expressed under stress conditions and which could be involved in the plant-pathogen incompatible reaction. Infiltration of suspension of *R. solanacearum* to tobacco leaves induced a condition similar to other stresses especially oxidative stress.

Generally when bacteria are introduced into plant tissues, defense gene activation may be more important than hypersensitive cell death in order to control pathogen growth (Jakobeck and Lindgran, 1993; Klement *et al.*, 2003).

Ascorbate peroxidase (APX) (TE2) was shown to be induced under incompatible

tobacco and *R. solanacearum* interaction. APX is a reactive oxygen species (ROSs) scavenging enzyme involved in regulation of intracellular ROS levels by reduction of H₂O₂. Excess amounts of H₂O₂ are known to cause oxidative damages to the host cells. H₂O₂ usually acts as signaling molecules in programmed cell death (PCD) under environmental stresses as well as in response to pathogen invasions (Qin *et al.*, 2008; Mittler *et al.*, 2004).

Reactive oxygen species, such as H₂O₂ play a central role in the activation of pathogen-induced PCD in plants. Findings suggest pathogen-induced PCD in tobacco is accompanied by the suppression of APX expression and reduction in cell capability to scavenge H₂O₂ so accumulation of H₂O₂ and the acceleration of PCD occurs (Mittler *et al.*, 1998). In DND reaction in this study we observed that up regulation in APX expression and H₂O₂ levels wasn't sufficient for cell death. Level and timing of H₂O₂ production in tobacco cells are critical points for APX regulation (de Pinto *et al.*, 2006) and it seems that level of H₂O₂ production increases before appearance of necrosis symptom, so antioxidant defense systems such as APX activity protect plant against damage of oxidative stress (Sarowar *et al.*, 2005).

Abscisic acid (ABA) response elements (TF11) are significant in plant response against abiotic and biotic stresses and ROS production (Mahalingam *et al.*, 2003; Sarowar *et al.*, 2005; Pei *et al.*, 2000). Over production of ABA response elements in the promoters of differentially expressed genes in stress conditions may reflect crosstalk among stress signaling pathway mediated by messengers like H₂O₂ (Mahalingam *et al.*, 2003).

Putative ML domain protein (TF13) belonging to the ML domain family is implicated in lipid recognition, particularly in the recognition of pathogen related products. These domain proteins are predicted to mediate diverse biological functions through interaction with specific lipids. (Marchler-Bauer *et al.*, 2011).

The Radical-induced Cell Death1 (TE3) protein is a key regulator of several ROS and abiotic stress-related responses and it interacts

with several transcription factors (Jaspers *et al.*, 2010). It displayed an enhanced cell death phenotype during incompatible interaction with the bacterial pathogen *Pseudomonas syringae* strain DC3000 (Overmyer *et al.* 2000a, b). Plants lacking this protein function display pleiotropic phenotypes including sensitivity to apoplastic ROS and salt, ultraviolet B and early flowering and senescence (Jaspers *et al.*, 2010).

Avr9/Cf-9 rapidly elicited (TF10) genes are predicted to encode regulatory proteins, including protein kinases and transcription factors (Baulcombe, 1999). Many of the Avr9/Cf-9 rapidly elicited genes encode putative signaling components and thus may play pivotal roles in the initial development of the defense response (Rowland *et al.*, 2005).

Wax2 (TE5) has a metabolic function associated with both cuticle membrane and wax synthesis (Chen *et al.*, 2003). Waxes are major constituents of the cuticle and play important roles in plant defenses against bacterial and fungal pathogens (Jenks *et al.*, 1994). Cutin and cuticular wax provide a physical barrier to pathogen ingress as the primary line of defense (Riederer, 2006).

Sesquiterpene synthases (TE8) are protein families which catalyze the conversion of sesquiterpene compounds in various plant species according to the demand and the environment (Kessler and Baldwin, 2001).

Induced sesquiterpenes can also form secondary chemical defenses (Bohlmann *et al.*, 1998) and be involved in plant reproductive systems by protecting against any attacks of insects, bacteria and fungi (Dorothea *et al.*, 2005). 12-15 copies of sesquiterpene synthase are found in the tobacco genome. It is also possible that these genes are regulated in response to the environment (Facchini and Chappell, 1992).

Our data support the hypothesis that DND phenotype in tobacco has some similarity especially in signaling process to more specific mechanism associated with induction of the hypersensitive reaction and it is distinct from general defense mechanisms.

Finally understanding the molecular basis of *R. solanacearum*-plant interactions by isolation and characterization of genes which are regulated in compatible or incompatible combinations could be useful for control of *R. solanacearum* by genetic engineering and breeding resistant cultivars. The bacterial wilt resistance is generally under polygenic control, while the control of resistance in *A. thaliana* is monogenic (Ishihara *et al.*, 2012). Research shows that interfamily transfer of R genes can provide a new strategy to develop pathogen-resistant crops (Narusaka *et al.*, 2013) and Quantitative resistance information could be used for generating markers for the breeding of resistant cultivars.

References

- Bachem, C. W. B., Oomen, R. J. F. and Visser, R. 1998. Transcript imaging with cDNA-AFLP: A step by step protocol. *Plant Molecular Biology Reporter*, 16: 157-173.
- Bassam, B. J., Caetano-Anolle's, G. and Gresshoff, P. M. 1991. Fast and sensitive silver staining of DNA in polyacrylamide gels. *Analytical Biochemistry*, 196: 80-83.
- Baulcombe, D. C. 1999. Fast forward genetics based on virus-induced gene silencing. *Current Opinion in Plant Biology*, 2: 109-113.
- Bohlmann, J., Meyer-Gauen, G. and Croteau, R. 1998. Plant terpenoid synthases: Molecular biology and phylogenetic analysis. *Proceedings of the National Academy of Sciences of the United States*, 5: 4126-4133.
- Buddenhagen, I. and Kelman, A. 1964. Biological and physiological aspects of bacterial wilt caused by *Pseudomonas solanacearum*. *Annual Review of Phytopathology*, 2: 203-230.
- Carney, B. F. and Denny, T. P. 1990. A cloned avirulence gene from *Pseudomonas solanacearum* determines incompatibility on *Nicotiana tabacum* at the host species level. *Journal of Bacteriology*, 172: 4836-4843.

- Carputo, D. and Barone, A. 2005. Ploidy level manipulations in potato through sexual hybridization. *Annals of Applied Biology*, 146 (1): 71-79.
- Carputo, D., Aversano, R., Barone, A., Di Matteo, A., Iorizzo, M. and Sigillo, L. 2009. Resistance to *Ralstonia solanacearum* of sexual hybrids between *Solanum commersonii* and *S. tuberosum*. *American Journal of Potato Research*, 86: 196-202.
- Chen, X., Goodwin, S. M., Boroff, V. L., Liu, X. and Jenks, M. A. 2003. Cloning and Characterization of the WAX2 Gene of Arabidopsis involved in Cuticle Membrane and Wax Production. *The Plant Cell*, 15: 1170-1185.
- Dahal, D., Heinz, D., Dorsselaer, A. V., Braun, H. P. and Wydra, K. 2009. Pathogenesis and stress related, as well as metabolic proteins are regulated in tomato stems infected with *Ralstonia solanacearum*. *Plant Physiology Biochemistry*. 47: 838-846.
- Daurelio, L., Tondo, M. L., Dunger, G., Gottig, N., Ottado, J. and Orellano, E. G. 2009a. Hypersensitive response, In: Narwal S. S., Catalan, A. N., Sampietro, D. A., Vattuone, M. A. and Polyticka, B. (Eds.), *Book on Plant Bioassay*, Houston, Studium press, pp. 187-206.
- Daurelio, L. D., Checa, K., Barrio, J. M., Ottado, J. and Orellano, E. G. 2009b. Characterization of *Citrus sinensis* type 1 mitochondrial alternative oxidase and expression analysis in biotic stress. *Bioscience Reports*, 30: 59-71.
- de Pinto, M.C., Paradiso, A., Leonetti, P. and De Gara, L. 2006. Hydrogen peroxide, nitric oxide and cytosolic ascorbate peroxidase at the crossroad between defence and cell death. *Plant Journal*, 48: 784-795.
- Dorothea, T., F. Chen, J. Petri, J. Gershenzon, and Pichersky, E. 2005. Two sesquiterpene synthases are responsible for the complex mixture of sesquiterpenes emitted from Arabidopsis flowers. *Plant Journal*. 42: 757-771.
- Esposito, N., Ovchinnikova, O. G., Barone, A., Zoina, A., Holst, O. and Evidente, A. 2008. Host and non-host plant response to Bacterial wilt in potato: role of the lipopolysaccharide isolated from *Ralstonia solanacearum* and molecular analysis of plant pathogen interaction. *Chemistry and Biodiversity*, 5: 2662-2675.
- Facchini, P. J. and Chappell, J. 1992. Gene family for an elicitor-induced sesquiterpene cyclase in tobacco. *Proceedings of the National Academy of Sciences of the United States*, 89: 11088-11092.
- Gao, G., Jin, L. P., Xie, K. Y. and Qu, D. Y. 2009. The potato StLTPa7 gene displays a complex Ca²⁺-associated pattern of expression during the early stage of potato-*Ralstonia solanacearum* interaction. *Molecular Plant Pathology*. 10: 15-27.
- Godiard, L., Ragueh, F., Froissard, D., Leguay, J. J., Grosset, J., Chartier, Y., Meyer, Y., and Marcp, Y. 1990. Analysis of the synthesis of several pathogenesis-related proteins in tobacco leaves infiltrated with water and with compatible and incompatible isolates of *Pseudomonas solanacearum*. *Molecular Plant-Microbe Interactions*, 3: 207-213.
- Hayward, A. C. 1991. Biology and epidemiology of bacterial wilt caused by *Pseudomonas solanacearum*. *Annual Review of Phytopathology*, 29: 65-87.
- Ishihara, T., Mitsuhashi, I., Takahashi, H. and Nakaho, K. 2012. Transcriptome Analysis of Quantitative Resistance-Specific Response upon *Ralstonia solanacearum* infection in Tomato. *PLoS One*, 7: e46763.
- Jakobek, J. L. and Lindgren, P. B. 1993. Generalised induction of defence responses in bean is not correlated with the induction of the hypersensitive reaction. *The Plant Cell*, 5: 49-56.
- Jaspers, P., Brosché, M., Overmyer, K. and Kangasjrvi, J. 2010. The transcription factor interacting protein RCD1 contains a novel conserved domain. *Plant Signaling and Behavior*, 5: 78-80.
- Jenks, M. A., Joly, R. J., Peters, P. J., Rich, P. J., Axtell, J. D. and Ashworth, E. N. 1994. Chemically induced cuticle mutation affecting epidermal conductance to water vapor and disease susceptibility in *Sorghum*

- bicolor* (L.) Moench. Plant Physiology, 105: 1239-1245.
- Kamoun, S. 2001. Nonhost resistance to *Phytophthora*: novel prospects for a classical problem. Current Opinion in Plant Biology, 4: 295-300.
- Kessler, A. and Baldwin, I. T. 2001. Defensive function of herbivore-induced plant volatile emissions in nature. Science, 291: 2141-2144.
- Kiba, A., Maimbo, M., Kanda, A., Tomiyama, H., Ohnishi, K. and Hikichi, Y. 2007. Isolation and expression analysis of candidate genes related to *Ralstonia solanacearum*-tobacco interaction. Plant Biotechnology, 24: 409-416.
- Klement, Z. 1982. Hypersensitivity, In: Mount, M. S. and Lacy, G. H. (Eds.), Phytopathogenic prokaryotes. Academic Press, New York, pp. 149-177.
- Klement, Z., Bozsó, Z., Kecskés, M. L., Besenyi, E., Czalleng, A., Ott, P. G. (2003): Local early induced resistance of plants as the first line of defence against bacteria. Pest Management Science, 59: 465-474.
- Lozano, J. C., and Sequeira, L. 1970. Prevention of the hypersensitive reaction in tobacco leaves by heat killed bacterial cells. Phytopathology, 60: 875-879.
- Mahalingam, R., Gomez-Buitrago, A. M., Eckardt, N., Shah, N., Guevara-Garcia, A., Day, P., Raina, R. and Fedoroff, N. V. 2003. Characterizing the stress/defense transcriptome of Arabidopsis. Genome Biology, 4: 20.
- Marchler-Bauer, A., Anderson, J. B., Chitsaz, F., Derbyshire, M. K., DeWeese-Scott, C., Fong, J. H., Geer, L. Y., Geer, R. C., Gonzales, N. R., Gwadz, M., He, S., Hurwitz, D. I., Jackson, J. D., Ke, Z., Lanczycki, C. J., Liebert, C. A., Liu, C., Lu, F., Lu, S., Marchler, G. H., Mullokandov, M., Song, J. S., Tasneem, A., Thanki, N., Yamashita, R. A., Zhang, D., Zhang, N. and Bryant, S. H. 2011. CDD: a Conserved Domain Database for the functional annotation of proteins. Nucleic Acids Research, 39: 225-229.
- Mittler, R., Freng, X. and Cohen, M. 1998. Post-Transcriptional Suppression of Cytosolic Ascorbate Peroxidase Expression during Pathogen-Induced Programmed Cell Death in Tobacco. The Plant Cell, 10: 461-473.
- Mittler, R., Vanderauwera, S., Gollery, M. and Van Breusegem, F. 2004. Reactive oxygen gene network of plants. Trends in Plant Science, 9: 490-498.
- Narusaka, M., Kubo, Y., Hatakeyama, K., Imamura, J., Ezura, H. and Nanasato, Y. 2013. Interfamily transfer of dual NB-LRR genes confers resistance to multiple pathogens. PLoS ONE, 8:e55954.
- Nouri, S., Bahar, M. and Fegan, M. 2009. Diversity of *Ralstonia solanacearum* strain causing bacterial wilt of potato in Iran. Plant Pathology, 58: 243-249.
- OEPP/ EPPO. 1990. EPPO Standards PM 3/ 26. *Ralstonia solanacearum*, inspection and test methods. Bulletin OEPP/EPPO Bulletin, 20: 255-262.
- OEPP/EPPO. 2004. Diagnostics protocols for regulated pests. *Ralstonia solanacearum*. Bulletin of the OEPP/EPPO, 34: 173-179.
- Overmyer, K., Tuominen, H., Kettunen, R., Betz, C., Langebartels, C., Sandermann, H. and Kangasjärvi, J. 2000a. Ozone-sensitive Arabidopsis *rcd1* mutant reveals opposite roles for ethylene and jasmonate signaling pathways in regulating superoxide-dependent cell death. Plant Cell, 12: 1849-1862.
- Overmyer, K., Tuominen, H., Kettunen, R., Betz, C., Langebartels, C., Sandermann, H. and Kangasjärvi, J. 2000b. Ozone-sensitive Arabidopsis *rcd1* mutant reveals opposite roles for ethylene and jasmonate signaling pathways in regulating superoxide-dependent cell death. Plant Cell, 12: 1849-1862.
- Qin, Y. M., Hu, C. Y. and Zhu, Y. X. 2008. The ascorbate peroxidase regulated by H₂O₂ and ethylene is involved in cotton fiber cell elongation by modulating ROS homeostasis. Plant Signaling and Behavior, 3: 19-196.
- Riederer, M. 2006. Biology of the plant cuticle, In: Riederer, M. and Muller, C. (Eds.), Biology of the Plant Cuticle. Oxford, UK, Blackwell publishers, pp. 1-8.

- Rowland, O., Ludwig, A. A., Merrick, C. J., Baillieul, F., Tracy, F. E., Durrant, W. E., Fritz-Laylin, L., Nekrasov, V., Sjolander, K. and Yoshioka, H. 2005. Functional analysis of Avr9/Cf-9 rapidly elicited genes identifies a protein kinase, ACIK1, that is essential for full Cf-9-dependent disease resistance in tomato. *Plant Cell*, 17: 295-310.
- Sarowar, S., Kim, Y. J., Kim, E. N., Kim, K. D., Hwang, B. K., Islam, R. and Shin, J. S. 2005. Overexpression of a pepper basic pathogenesis-related protein 1 gene in tobacco plants enhances resistance to heavy metal and pathogen stresses. *Plant Cell Reports*, 24: 216-224.
- Schacht, T., Unger, C., Pich, A. and Wydra, K. 2011. Endo and exopolygalacturonases of *Ralstonia solanacearum* are inhibited by polygalacturonase inhibiting protein activity in tomato stem extracts. *Plant Physiology and biochemistry*, 49: 377-387.
- Thordal-Christensen, H. 2003. Fresh insights into processes of non-host resistance. *Current Opinion in Plant Biology*, 6: 351-357.
- Vasse, J., Frey, P. and Trigalet, A. 1995. Microscopic studies of intercellular infection and protoxylem invasion of tomato roots by *Pseudomonas solanacearum*. *Molecular Plant-Microbe Interactions*, 8: 241-251.

آنالیز ترانسکریپتوم توتون در واکنش به آلودگی *Ralstonia solanacearum*

کبری مسلم خانی^۱، جواد مظفری^{۲*}، مسعود شمس بخش^۲ و ابراهیم محمدی گل تپه^۴

۱- مؤسسه تحقیقات ثبت و گواهی بذر و نهال، سازمان تحقیقات، آموزش و ترویج کشاورزی، کرج، ایران.

۲- مؤسسه تحقیقات اصلاح و تهیه نهال و بذر، سازمان تحقیقات، آموزش و ترویج کشاورزی، کرج، ایران.

۳- گروه بیماری شناسی گیاهی، دانشکده کشاورزی، دانشگاه تربیت مدرس، تهران، ایران.

* پست الکترونیکی نویسنده مسئول مکاتبه: j.mozafari@yahoo.com

دریافت: ۵ خرداد ۱۳۹۵؛ پذیرش: ۱۹ آبان ۱۳۹۵

چکیده: یکی از بهترین استراتژی‌ها برای کنترل بیماری پژمردگی باکتریایی با عامل *Ralstonia solanacearum* استفاده از ارقام مقاوم اصلاح شده است. کسب اطلاعات در زمینه بیان ژن‌های دفاعی باعث ایجاد نگرش جدید برای اصلاح مقاومت گیاه علیه پاتوژن‌ها می‌شود. تحقیق حاضر با بهره‌گیری از روش cDNA-AFLP به مطالعه ژن‌های القاء شده در واکنش دفاعی از نوع DND (Defense No Death) در گیاه توتون علیه *R. solanacearum* پرداخته است. در این روش با استفاده از پنج ترکیب پرایمری ۱۳۲۰ قطعه مشتق از رونوشت (TDF) مشاهده شد که از بین آن‌ها ۱۰۱ قطعه در زمان‌های صفر، ۲۴، ۴۸ و ۷۲ ساعت پس از آلوده‌سازی بیان متفاوت نشان دادند. بیش‌ترین تفاوت بیان ژن‌ها در ۴۸ ساعت پس از آلوده‌سازی مشخص شد. پس از توالی‌یابی، TDFهای توالی‌یابی شده بیش‌ترین شباهت را با ژن‌های دخیل در پیام‌رسانی، تنظیم و دفاعی داشته‌اند. القاء ژن‌ها در فنوتیپ DND در توتون خصوصاً در فرایند پیام‌رسانی شباهت با واکنش فوق حساسیت دارد و متفاوت از مکانیسم دفاعی عمومی در گیاه است.

واژگان کلیدی: توتون، *Ralstonia solanacearum*، ترانسکریپتوم و تعامل