

Abscisic Acid Improves Chilling-Induced Oxidative Stress in *Trichosanthes kirilowii* Maxim Seedlings

G. H. Yao¹, P. P. Gao¹, Y. P. Wang¹, L. H. Wang¹, G. D. Xu¹, and P. Liu^{1*}

ABSTRACT

Trichosanthes kirilowii, an important economic plant in China, is sensitive to chilling. To investigate the effect of abscisic acid (ABA) treatment on the chilling tolerance of *Trichosanthes kirilowii* Maxim, different concentrations of ABA were sprayed on *Trichosanthes kirilowii* leaves and the resulting catalase (CAT) and superoxide dismutase (SOD) activities and the malondialdehyde (MDA) content in the leaves were determined. The results indicated that at 4 °C, the CAT and SOD activities increased at first and then decreased with increasing ABA concentration. By contrast, the MDA content decreased at first and then increased. They both had an extreme value when sprayed with 5.0 or 7.5 mg L⁻¹ ABA. A real-time polymerase chain reaction was performed to investigate the influence of exogenous ABA on the CAT gene expression of *Trichosanthes kirilowii* leaves. The results indicated that at 4 °C, the CAT relative gene expression showed a high degree of positive correlation with the enzyme activities of CAT and SOD, and a negative correlation with MDA content. These results led to three conclusions. First, exogenous ABA exhibits significant effect on the chilling tolerance of *Trichosanthes kirilowii*. Second, exogenous ABA significantly increases the enzyme activities of CAT and SOD under cold environments. Finally, under cold environments and the effect of ABA, the relative gene expression of catalase 2 (CAT2) gene was found to play an important role in the enhancement of the chilling tolerance of *Trichosanthes kirilowii* leaves.

Keywords: Catalase, Cold, Malondialdehyde, Real time PCR, Superoxide dismutase.

INTRODUCTION

Various tolerance mechanisms have been suggested on the basis of the biochemical and physiological changes related to chilling injury. As temperature is reduced, a specific temperature determined by the ratio of saturated to unsaturated fatty acids accelerates the conversion of lipids of a liquid-crystalline condition into that of a solid condition in plant cell membranes (Campos *et al.*, 2003; Partelli *et al.*, 2011). The conversion of fatty acid may give rise to chilling resistance at lower temperatures in the plant cells (Luciana *et al.*, 2010).

ABA-related experiments generally take MDA as an indicator of cell damage (Hung

and Kao, 2003; Bueno *et al.*, 1998; Lu *et al.*, 2009). In the current study, MDA was used as an indicator of chilling tolerance, in which lower MDA content indicated better chilling tolerance. ABA induces stomata cells in plant leaves to shut to reduce transpiration, which plays an important role in alleviating drought-stress (Irving *et al.*, 1992; Lee *et al.*, 1999; Pei *et al.*, 2000; Murata *et al.*, 2001). Sripinyowanich *et al.* (2010) stated that ABA can increase the salt-stress tolerance of indica rice (*Oryza sativa* L.), while Wan and Li (2006) stated that ABA can increase the water-stress tolerance of Arabidopsis. ABA also plays an important role in enhancing the chilling tolerance and the cold-stress tolerance of

¹ Laboratory of Botany, Zhejiang Normal University, People's Republic of China.

*Corresponding author; e-mail: sky79@zjnu.cn



fruits and seeds (Rikin *et al.*, 1979; Wang and Buta, 1994). Moreover, increased endogenous ABA content can also reduce cold stress-related damage (Wang, 1991). However, the effects of exogenous ABA on the chilling tolerance of *Trichosanthes kirilowii* in cold-stress environments have not been reported.

Large amounts of reactive oxygen species generated in plants in cold-stress environments destroy the plants' chloroplast, cell membrane, protein, and nucleic acid, among others (Hu *et al.*, 2005; Zhang *et al.*, 2009; Heidari *et al.*, 2012). Catalase (CAT) and superoxide dismutase (SOD) play important roles in prevention of the poisoning of reactive oxygen species (Lee and Lee, 2000; Mizuno *et al.*, 1998). In plants, SOD helps clear up O_2^- to generate O_2 and H_2O_2 , which can then be decomposed into H_2O and O_2 . This process is catalyzed by ascorbate peroxidase (APX) in the chloroplast (Miyake and Asada, 1994). The effects of exogenous ABA on CAT and SOD in *Trichosanthes kirilowii* leaves have not been reported.

CAT is an iron porphyrin enzyme that catalyzes the decomposition of hydrogen peroxide into water and oxygen. CAT is involved in the CAT and SOD enzyme systems that clear up reactive oxygen species (Purev *et al.*, 2010). Most of the higher plant species have three kinds of CAT genes (Iwamoto *et al.*, 2000). For example, Arabidopsis has catalase1 (CAT1), catalase2 (CAT2), and catalase3 (CAT3) (Frugoli *et al.*, 1996). CAT genes play important roles in resisting stress (Guan and Scandalios, 1993). Whether or not the three kinds of CAT genes found in *Trichosanthes kirilowii* play an important role in the chilling tolerance of *Trichosanthes kirilowii*, and, if so, which one is most important has not been reported.

Trichosanthes kirilowii is a type of liana that belongs to the Cucurbitaceae family whose root tuber is used to treat diabetes (Zhou *et al.*, 2002). Moreover, *Trichosanthes kirilowii* can also effectively curb the AIDS virus and possesses some

anti-cancer properties (Xie, 2000), giving it high medicinal value. However, *Trichosanthes kirilowii* has a low chilling tolerance that makes it susceptible to frost damage, which has a negative impact on the following year's yield. Enhancing the cold hardiness of *Trichosanthes kirilowii* is one of the priorities in its cultivation.

Therefore, the current study aims to reveal the following three points: (1) whether or not exogenous ABA affects the chilling tolerance of *Trichosanthes kirilowii*, (2) whether or not exogenous ABA affects CAT and SOD, and (3) whether or not the three kinds of CAT genes present in *Trichosanthes kirilowii* play important roles in enhancing chilling tolerance, and if so, which one is the most important.

MATERIALS AND METHODS

Biological Materials

The seeds were purchased from Sanmenxia City, China. When a *Trichosanthes kirilowii* grew its third true leaf, it was moved into a complete solution culture. After two weeks cultivation, the *Trichosanthes kirilowii* plants of approximately the same growth were selected for the subsequent experiments. The *Trichosanthes kirilowii* plants were divided into seven groups numbered 1 to 7. Group numbers 3 to 7 were sprayed thrice daily with 2.5, 5.0, 7.5, 10.0 and 5.0 mg L⁻¹ of ABA, respectively. After 2 days, group numbers 2 to 6 were placed in a climate chamber (Radford Technology Company, Ningbo, China) under an environment of 4±1°C for 3 days. Subsequently, group numbers 1 and 7 were placed in a similar climate chamber in an environment of 25±1°C for 3 days, too. In the climate chambers, all plants were given illumination for 16 h. After 3 days in the climate chamber, the leaves were harvested for further experimentation. Treatments were divided into seven groups including CK1:

Sprayed no ABA at 25°C; T1: Sprayed no ABA at 4°C; T2: Sprayed 2.5 mg L⁻¹ ABA at 4°C; T3: Sprayed 5.0 mg L⁻¹ ABA at 4°C; T4: Sprayed 7.5 mg L⁻¹ ABA at 4°C; T5: Sprayed 10.0 mg L⁻¹ ABA at 4°C, CK2: Sprayed 5 mg L⁻¹ ABA at 25°C.

Enzyme Assay

MDA was measured by the barbituric acid chromogenic method (Zhao and Li, 1999). Enzyme assay of CAT and SOD was carried out according to Lee and Lee (2000).

Primer Design

Based on the sequences of homologous species, the degenerate primers were designed by the National Center for Biotechnology Information (NCBI). The length of *CAT2* gene fragment was 330 bp. F: 5'-TAATGCTCCWAAGTGTCTCA-3', R: 5'-GCCTGAGWCCA-GTAYGWGATCCA-3'. Actin2 (DQ115882) fragment, with a gene length of 117 bp, was chosen as the reference gene. The primers of Actin2 were F: 5'-GAAGGAATAACCGCT-CAG-3', R: 5'-ACACAGTCCCATCTACGAG-3'. The primers were designed by TAKARA (Dalian, China).

Total RNA Extraction

Trichosanthes kirilowii leaves were ground in liquid nitrogen, and then lysed in the extraction buffer. Chloroform: isoamyl alcohol (24:1) was added, and the mixture centrifuged to obtain the upper phase. Absolute ethanol (2× volume) and 0.1× volume of NaCl (5M) were added. After centrifugation, the pellet was re-suspended in DEPC-treated water. An equal volume of TE-saturated phenol (pH 8.0): chloroform: isoamyl alcohol (25:24:1) was added, and the phases separated by centrifugation at

room temperature. To the upper phase, 2× volume of absolute ethanol and 0.1× volume NaCl (5M) were added and the solution was centrifuged. The RNA pellet was re-suspended in DEPC-treated water.

Reverse-transcription and PCR Amplification

First-strand cDNA synthesis was performed, following the manufacturer's (Invitrogen Life Technologies, Carlsbad, CA) instructions, using 2 µg of the total RNA treated with DNaseI (TAKARA, Dalian, China), 200 units of Avian Myeloblastosis Virus (AMV) reverse transcriptase (Invitrogen Life Technologies), 50 units of RNase inhibitor (RNase out, Invitrogen Life Technologies), 1 mM dNTPs, and 2.5 µM random primers (Sigma-Aldrich, St. Louis, MO). The mix for reverse transcriptase (20 µl) was incubated for 50 minutes at 37°C. The PCR mix (25 µl) contained 2 µl of cDNA (10% of the first-strand reaction, corresponding to approximately 100 ng of the total RNA), 4 µl PCR buffer (5×, Invitrogen Life Technologies), 0.2 mM dNTPs, 0.5 µM of each primer, 1.5 mM MgCl₂, and 0.5 units of Taq polymerase (PlatinumTaq polymerase, Invitrogen Life Technologies). Amplifications of the target gene were conducted in a Genetic Thermal Cycler with 40 cycles of 94°C for 30 seconds, 40°C for 2 minutes, and 72°C for 30 seconds, with a 5 minutes extension at 72°C. Amplifications of the reference gene were conducted in a Genetic Thermal Cycler with 36 cycles of 95°C for 30 seconds, 57°C for 45 seconds, and 72°C for 1 minute, with a 6 minute extension at 72°C.

Real-time PCR Amplification

Degenerate primers were used to clone a *CAT2* gene fragment with length of approximately 330 bp. The sequencing results were entered into the NCBI for the homology comparison. The results were found to have 87% similarity with *Cucurbita pepo* mRNA and *CAT2*, ensuring that the



cloned fragment belonged to the *Trichosanthes kirilowii* CAT2 gene. A semi-quantitative PCR was then performed based on the sequencing results. The 330 bp long fragment was cloned to reduce the interference of non-specific clone fragments. The specific primers of the CAT2 gene were designed as follows: F: 5'-TAATGCTCCTAAGTGTCTCA-3', R: 5'-GCCTGAGTCCAGTACGAGATCCA-3'.

The PCR mixture contained 1 μ l of diluted cDNA, 5 μ l of 2 \times SYBR Green PCR Master Mix, and 200 nM of each gene-specific primer in a final volume of 20 μ l. Real-time PCRs were performed using an ABI Prism 7,000 Sequence Detection System and the appropriate software (PE Applied Biosystems, USA). All PCRs were performed under the following conditions: 2 minutes at 95°C, 40 cycles of 10 seconds at 94°C, 10 seconds at 57°C, and elongated at 72°C for 40 seconds in 96-well optical reaction plates (Applied Biosystems, USA). The specificity of the PCR products were verified using a melting curve analysis (60 to 95°C) after 40 cycles and agarose gel electrophoresis. The levels of CAT2 transcripts were normalized by endogenous Actin transcripts. Each set of experiments

was repeated three times.

RESULTS

Determination of MDA

The concentration of MDA in leaves was very low when plants were grown under 25°C. By contrast, this value turned to be higher when plants were moved to 4°C for 3 days. The accumulation of MDA in the recovered plants suggests that the plasma membrane in leaves might be damaged during 4°C condition (Figure 1).

The induction of MDA in plant leaves under 4°C condition was repressed by 2.5 mg L⁻¹ ABA treatment, and this repression was more significant in the presence of 5.0 mg L⁻¹ ABA. However, further increase in the concentration of ABA did not play more effective role in reducing the MDA content as shown by the abundant value of MDA in 7.5 mg L⁻¹ ABA treated plants when compared with that in 5.0 mg L⁻¹ ABA treated plants, and this value was even higher in 10.0 mg L⁻¹ ABA treated groups. These results suggested that the optimal

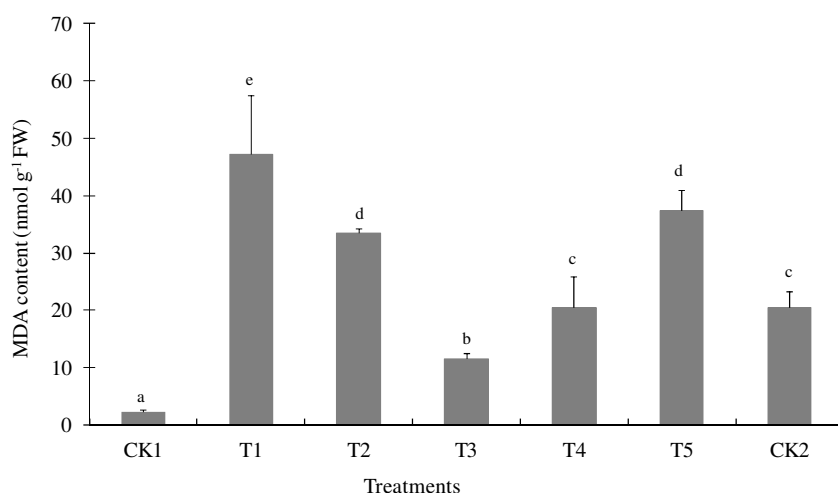


Figure 1. Measurement of MDA in extracts of leaves sprayed with different concentrations of ABA. We took MDA as indicator of chilling tolerance. The content was lower, the chilling tolerance was better. Value with the same letter are not significantly different at $P \leq 0.05$ level, according to Duncan's multiple range test. Data are Means \pm SD (n= 3). CK1: Sprayed no ABA at 25°C; T1: Sprayed no ABA at 4°C; T2: Sprayed 2.5 mg L⁻¹ ABA at 4°C; T3: Sprayed 5.0 mg L⁻¹ ABA at 4°C; T4: Sprayed 7.5 mg L⁻¹ ABA at 4°C; T5: Sprayed 10.0 mg L⁻¹ ABA at 4°C, CK2: Sprayed 5 mg L⁻¹ ABA at 25°C.

concentration of ABA in blocking the induction of MDA at 4°C might be 5.0 mg L⁻¹.

Subsequently, we attempted to determine whether the 5.0 mg L⁻¹ ABA was functioning in reducing MDA content under normal condition. The results showed that externally applied ABA increased the MDA content when grown under 25°C condition, rather than decreasing this value (Figure 1). This suggested that the extra ABA was not effective in preventing plant from producing MDA; on the contrary, breaking the balance of ABA was even harmful for plant growth.

Catalase Activity Assay

One unit of CAT is defined as the amount of enzyme which liberates the peroxide oxygen from 1 μmol H₂O₂ solution in 1 minute at 25°C (Xing and Ding, 1981).

The CAT activity in leaves was high when plants were grown under 25 °C, regardless of spraying 5.0 mg L⁻¹ ABA or not. But, the CAT activity turned to be lower when plants were moved to 4°C for 3 days. The CAT activity did not increase significantly when sprayed with 2.5 mg L⁻¹ ABA under 4°C condition. When the ABA concentration was

increased to 5.0 mg L⁻¹, we could see a significant mounting of CAT activity (Figure 2). But the concentration increased to 7.5 mg L⁻¹ could not provide a higher mounting of CAT activity than 5.0 mg L⁻¹. The treatment sprayed with 10.0 mg L⁻¹ ABA appeared worse, it only had a similar mounting of CAT activity compared with the plants sprayed with 2.5 mg L⁻¹ ABA. Therefore, we thought that a comfortable concentration of ABA in increasing the CAT activity at 4°C might be 5.0 mg L⁻¹.

Total SOD Activity Assay

One unit of SOD is defined as the amount of enzyme which causes a 50% decrease of the SOD-inhibitable nitrotetrazolium blue chloride (NBT) reduction (Beyer and Fridovich, 1987).

In the plants that had not been sprayed with ABA, chilling stress did not induce a significant increase in total SOD activity; whereas in plants sprayed with ABA at 4°C, the SOD activity gradually increased. The value reached its extreme in the concentration of 5.0 mg L⁻¹. After that, the activity was gradually decreased. Under the condition of 4°C, the pattern of changes in

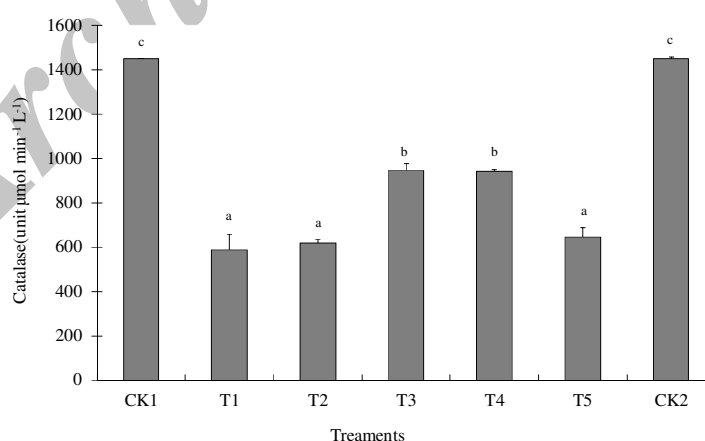


Figure 2. Activity of CAT in leaves sprayed with different concentrations of ABA. One unit of catalase is defined as the amount of enzyme which liberates the peroxide oxygen from 1 μmol H₂O₂ solution in 1 minute at 25°C. Value with the same letter are not significantly different at *P* 0.05 level, according to Duncan's multiple range test. Data are Means±SD (n= 3). CK1: Sprayed no ABA at 25°C; T1: Sprayed no ABA at 4°C; T2: Sprayed 2.5 mg L⁻¹ ABA at 4°C; T3: Sprayed 5.0 mg L⁻¹ ABA at 4°C; T4: Sprayed 7.5 mg L⁻¹ ABA at 4°C; T5: Sprayed 10.0 mg L⁻¹ ABA at 4°C, CK2: Sprayed 5 mg L⁻¹ ABA at 25°C.

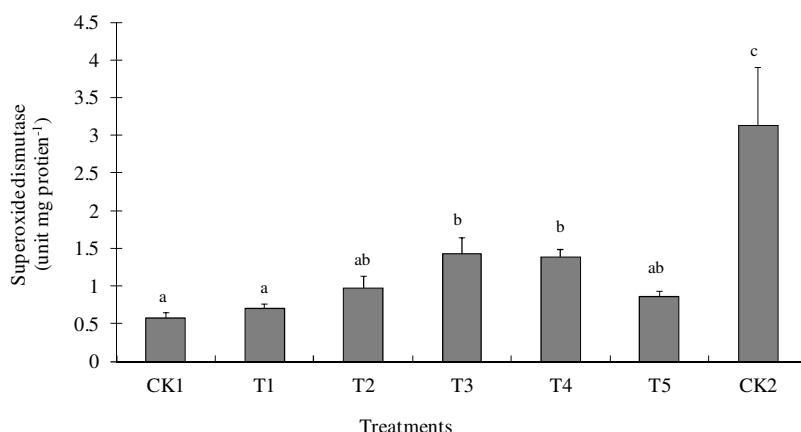


Figure 3. Activity of SOD in leaves sprayed with different concentrations of ABA. One unit of SOD is defined as the amount of enzyme which causes a 50% decrease of the SOD-inhibitable NBT reduction. Value with the same letter are not significantly different at $P \leq 0.05$ level, according to Duncan's multiple range test. Data are Means \pm SD ($n=3$). CK1: Sprayed no ABA at 25°C; T1: Sprayed no ABA at 4°C; T2: Sprayed 2.5 mg L⁻¹ ABA at 4°C; T3: Sprayed 5.0 mg L⁻¹ ABA at 4°C; T4: Sprayed 7.5 mg L⁻¹ ABA at 4°C; T5: Sprayed 10.0 mg L⁻¹ ABA at 4°C, CK2: Sprayed 5 mg L⁻¹ ABA at 25°C.

the SOD activity was very similar to that of changes in the CAT activity (Figure 3). To increase the SOD activity at 4°C, spraying 5.0 mg L⁻¹ ABA would be most acceptable. However, plants sprayed with 5.0 mg L⁻¹ ABA had a significantly higher SOD activity at 25°C compared to those at 4°C. We could conclude that chilling may be unfriendly to ABA in increasing SOD activity of *Trichosanthes kirilowii* leaves.

Real-time PCR Assay

The results of the semi-quantitative PCR showed that the gene expressions of the different groups had significant differences. Thus, real-time PCR was conducted to validate the results. The primers were similar to those used in the semi-quantitative PCR. The melting curve did not contain a hybrid peak, indicating the absence of pollution or impurities in the amplification. As such, the gene expression was stable and the results of the real-time PCR were reliable.

The CAT2 relative gene expression in leaves turned to be extremely low when plants were sprayed with 5.0 mg L⁻¹ ABA at 25°C for 3 days. Under the condition of 4°C,

from 0 to 5.0 mg L⁻¹, as the concentration of ABA increased, the CAT2 relative gene expression in plant leaves gradually increased. But, beyond 5.0 mg L⁻¹ ABA, the value of CAT2 relative gene expression in 7.5 mg L⁻¹ and 10.0 mg L⁻¹ ABA treated groups decreased compared with that in 5.0 mg L⁻¹ ABA treated plants (Figure 4). However, in chilling condition, ABA could help CAT2 gene get more expression. At 4°C, the CAT2 relative gene expression had a high degree of positive correlation with the CAT activity (Figures 2 and 4).

DISCUSSION

MDA is an indicator of plant lipid peroxidation (Lu *et al.*, 2009). Hung and Kao (2003; 2004) stated that at room temperature, ABA increases MDA content in rice leaves. This result is in line with the results of the current study, wherein at 25°C, the *Trichosanthes kirilowii* leaves treated with ABA had higher MDA content than the untreated groups (Figure 1). In this study, the MDA content was expected to increase when subjected to a cold environment or when treated with ABA only. However, the chilling and ABA treatments were not

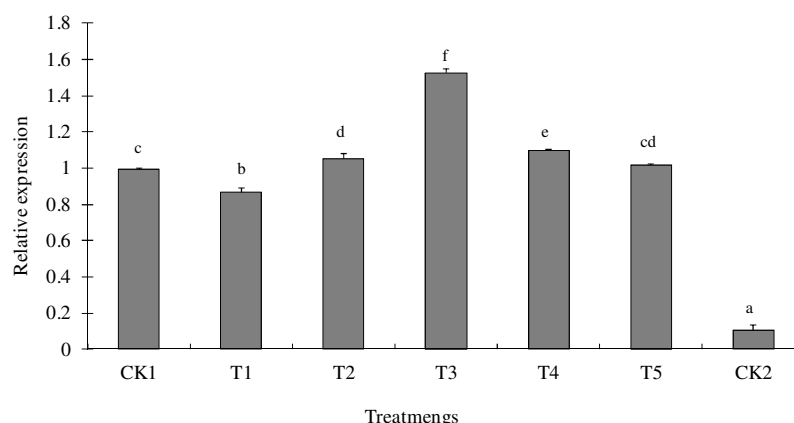


Figure 4. Relative expression of CAT2 mRNA in leaves sprayed with different concentrations of ABA. Value with the same letter are not significantly different at $P \leq 0.05$ level, according to Duncan's multiple range test. Data are Means \pm SD (n= 3). CK1: Sprayed no ABA at 25°C; T1: Sprayed no ABA at 4°C; T2: Sprayed 2.5 mg L⁻¹ ABA at 4°C; T3: Sprayed 5.0 mg L⁻¹ ABA at 4°C; T4: Sprayed 7.5 mg L⁻¹ ABA at 4°C; T5: Sprayed 10.0 mg L⁻¹ ABA at 4°C, CK2: Sprayed 5 mg L⁻¹ ABA at 25°C.

synergistic when applied together. Lee and Lee (2000) stated that the chilling stress in cucumber leaves increased SOD activity, indicating a positive effect on the removal of reactive oxygen species. This result is consistent with the results of the current study, wherein the MDA content in the *Trichosanthes kirilowii* leaves was lower at 4°C than at 25°C, despite both groups having been treated with 5.0 mg L⁻¹ ABA (Figure 1). Therefore, exogenous ABA can obviously affect the chilling tolerance of *Trichosanthes kirilowii*.

Cold tolerance and the activity of CAT do not always show a positive correlation. In some research, chilling decreases the CAT activity, but increase the tolerance of plants (Marc *et al.*, 1994). However, in most condition, they show a positive correlation. Hung and Kao (2004) stated that the addition of ABA increased the CAT and SOD activities of rice leaves. The current study found a high positive correlation between CAT and SOD at 4°C. Also, both CAT and SOD had a significant negative correlation with MDA content, which is a typical indicator of chilling tolerance (Figures 1-3). Therefore, the exogenous ABA can enhance the chilling tolerance of *Trichosanthes kirilowii* by raising the CAT and SOD enzyme activities in its leaves. This result is

in line with the results of the current study, wherein the CAT activity in *Trichosanthes kirilowii* leaves was higher at 25°C than at 4°C.

Hu *et al.* (2010) stated that CAT2 may play an important role in the scavenging of H₂O₂ produced under stressful conditions. Real-time quantitative PCR was conducted to further investigate the role of CAT2 in the chilling tolerance of *Trichosanthes kirilowii*. At 4°C, the CAT2 relative gene expression showed a positive correlation with CAT enzyme activity, consequently increasing the chilling tolerance (Figures 2 and 4). *Trichosanthes kirilowii* leaves sprayed with ABA at 25°C were highly damaged. Ling *et al.* (2000) stated that only the CAT1 and CAT3 transcripts in young maize leaves increased in response to wounding. Scandalios *et al.* (2000) stated that the *Car1* gene product can become inhibited at elevated temperatures when the trans-acting gene locus *Car1* regulates the *CAT2* gene activity levels in maize leaves. The current study showed that at 25°C, the *Trichosanthes kirilowii* sprayed with ABA had a low *CAT2* gene expression, but high enzyme activity (Figures 2 and 4). This result can be attributed to the fact that the *CAT2* gene no longer was the main form of the *CAT* gene expression. However, at 4°C, the ABA not



only assisted the chilling in damaging the cells, but also alleviated the damage caused by chilling. Thus, at 4°C, the gene expression of *CAT2* gene induced by ABA plays an important role in enhancing the chilling tolerance of *Trichosanthes kirilowii*.

At 25°C, no significant differences in CAT enzyme activities were observed between the leaves treated with ABA and the untreated leaves (Figure 2). However, the untreated *Trichosanthes kirilowii* leaves showed visibly lower SOD enzyme activity than the treated ones at 25°C (Figure 3). Thus, at 25°C, ABA treatment had no obvious effect on CAT activity, but had significant effect on SOD, probably because the CAT activity was not able to clear up the H₂O₂ that led to membrane damage and intracellular substance leak under the condition of the ABA damaging the reactive oxygen species. Other mechanisms, such as the APX catalysis, may play important roles in the process of clearing up the H₂O₂. In the chloroplast, H₂O₂ mainly depended on APX and on its corresponding circulatory system, which was called ascorbic acid-glutathione (AsA-GSH), when the CAT was insufficient (Esfandiari et al., 2007).

In summary, exogenous ABA was shown able to significantly enhance the chilling tolerance of *Trichosanthes kirilowii*. Exogenous ABA can significantly increase the CAT and SOD enzyme activities of *Trichosanthes kirilowii* leaves under cold environments. The *CAT2* gene plays an important role in the enhancement of the chilling tolerance induced by ABA. The mechanism of the transformation of the three kinds of *CAT* genes during chilling stress requires further research.

ACKNOWLEDGEMENTS

This study was financially supported by Natural Science Foundation of Zhejiang Province of China (Y5100390) and Public interest research and agricultural projects of Zhejiang Province of China (2011C22053).

REFERENCE

1. Beyer, W. F. and Fridovich, I. 1987. Assaying for Superoxide Dismutase Activity: Some Large Consequences of Minor Changes in Conditions. *Anal. Biochem.*, **161(2)**: 559-566.
2. Bueno, P., Piqueras, A., Kurepa, J., Savoure, A., Verbruggen, N., Montagu, M. Van and Inze, D. 1998. Expression of Antioxidant Enzymes in Response to Abscisic Acid and High Osmoticum in Tobacco BY-2 cell Cultures. *Plant Sci.*, **138(1)**: 27-34.
3. Campos, P. S., Quartin, V., Ramalho, J. C. and Nunes, M. A. 2003. Electrolyte Leakage and Lipid Degradation Account for Cold Sensitivity in Leaves of *Coffea* sp. *Plants. J. Plant Physiol.*, **160**: 283-292.
4. Esfandiari, E., Shekari, F., Shekari, F. and Esfandiari M. 2007. The Effect of Salt Stress on Antioxidant Enzymes' Activity and Lipid Peroxidation on the Wheat Seedling. *Not. Bot. Hort. Agrobot. Cluj*, **35(1)**: 48-56.
5. Frugoli, J. A., Zhong, H. H., Nuccio, M. L., McCourt, P., McPeck, M. A., Thomas, T. L. and McClung, C. R. 1996. Catalase is Encoded by a Multigene Family in *Arabidopsis thaliana* (L.). *Plant Physiol.*, **112(1)**: 327-336.
6. Guan, L. M. and Scandalios, J. G. 1993. Characterization of the Catalase Antioxidant Defense Gene *Cat1* of Maize, and Its Developmentally Regulated Expression in Transgenic Tobacco. *Plant J.*, **3(4)**: 527-536.
7. Guan, L. M. and Scandalios, J. G. 2000. Hydrogen Peroxide-mediated Catalase Gene Expression in Response to Wounding. *Free Radical Biol. Med.*, **28(8)**: 1182-1190.
8. Heidari, B., Pessarakli, M., Dadkhodaie, A. and Daneshnia, N. 2012. Reactive Oxygen Species-mediated Functions in Plants under Environmental Stresses. *J. Agric. Sci. Tech.*, **2(2b)**: 159.
9. Hu, X. L., Jiang, M. Y., Zhang, A. Y. and Lu, J. 2005. Abscisic Acid-induced Apoplastic H₂O₂ Accumulation Up-regulates the Activities of Chloroplastic and Cytosolic Antioxidant Enzymes in Maize Leaves. *Planta*, **223(1)**: 57-68.
10. Hu, Y. Q., Liu, S., Yuan, H. M., Li, J., Yan, D. W., Zhang, J. F. and Lu, Y. T. 2010. Functional Comparison of Catalase Genes in the Elimination of Photorespiratory H₂O₂ Using Promoter and 3'-untranslated Region Exchange Experiments in the *Arabidopsis*

- CAT2 Photorespiratory Mutant. *Plant Cell Environ.*, **33(10)**: 1656-1670.
11. Hung, K. T. and Kao, C. H. 2003. Nitric Oxide Counteracts the Senescence of Rice Leaves Induced by Abscisic Acid. *J. Plant Physiol.*, **160(8)**: 871-879.
 12. Hung, K. T. and Kao, C. H. 2004. Hydrogen Peroxide Is Necessary for Abscisic Acid-induced Senescence of Rice Leaves. *J. Plant Physiol.*, **161(12)**: 1347-1357.
 13. Irving, H. R., Gehring, C. A. and Parish, R. W. 1992. Changes in Cytosolic pH and Calcium of Guard Cells Precede Stomatal Movements. *Proc. Natl. Acad. Sci. USA*, **89**: 1790-1794.
 14. Iwamoto, M., Higo, H. and Higo, K. 2000. Differential Diurnal Expression of Rice Catalase Genes: the 5'-flanking Region of CatA Is Not Sufficient for Circadian Control. *Plant Sci.*, **151(1)**: 39-46.
 15. Lee, S., Choi, H., Suh, S., Doo, I. S., Oh, K. Y. and Choi, E. J. 1999. Oligogalacturonic Acid and Chitosan Reduce Stomatal Aperture by Inducing the Evolution of Reactive Oxygen Species from Guard Cells of Tomato and *Commelina communis*. *Plant Physiol.*, **121(1)**: 147-152.
 16. Lee, D. H. and Lee, C. B. 2000. Chilling Stress-induced Changes of Antioxidant Enzymes in the Leaves of Cucumber: In Gel Enzyme Activity Assays. *Plant Sci.*, **159(1)**: 75-85.
 17. Lu, S. Y., Su, W., Li, H. H. and Guo, Z. F. 2009. Abscisic Acid Improves Drought Tolerance of Triploid Bermudagrass and Involves H₂O₂ and NO-induced Antioxidant Enzyme Activities. *Plant Physiol. Biochem.*, **47(2)**: 132-138.
 18. Luciana M. N., Alana C., Fernando P. M., Dirce F. M., 2010. Chill-induced Changes in Fatty Acid Composition of Tonoplast Vesicles from Hypocotyls of *Vigna unguiculata* (L.) Walp. *Braz. J. Plant Physiol.*, **22(1)**: 69-72.
 19. Marc D. A., Tottempudi K. P., Barry A. M. and Cecil R. S. 1994. Differential Gene Expression in Chilling-acclimated Maize Seedlings and Evidence for the Involvement of Abscisic Acid in Chilling Tolerance. *Plant Physiol.*, **105**: 331-339.
 20. Miyake, C. and Asada, K. 1994. Ferredoxin-dependent Photoreduction of the Monodehydroascorbate Radical in Spinach Thylakoids. *Plant Cell Physiol.*, **35(4)**: 539-549.
 21. Mizuno, M., Kamei, M. and Tsuchida, H. 1998. Ascorbate Peroxidase and Catalase Cooperate for Protection against Hydrogen Peroxide Generated in Potato Tubers during Low Temperature Storage. *Biochem. Mol. Biol. Int.*, **44(4)**: 717-726.
 22. Murata, Y., Pei, Z. M., Mori, I. C. and Schroeder, J. I. 2001. Abscisic Acid Activation of Plasma Membrane Ca²⁺ Channels in Guard Cells Requires Cytosolic NAD(P)H and Is Differentially Disrupted Upstream and Downstream of Reactive Oxygen Species Production in *abi1-1* and *abi2-1* Protein Phosphatase 2C Mutants. *Plant Cell*, **13**: 2513-2523.
 23. Partelli, F. L., Batista-Santos, P., Scotti-Campos, P., Pais, I. P., Quantin, V. L., Vieira, H. D. and Ramalho, J. C. 2011. Characterization of the Main Lipid Components of Chloroplast Membranes and Cold Induced Changes in *Coffea* spp. *Environ. Exp. Bot.*, **74(1)**: 194-204.
 24. Pei, Z. M., Murata, Y., Benning, G., Thomine, S., Klusener, B. and Allen, G. J. 2000. Calcium Channels Activated by Hydrogen Peroxide Mediate Abscisic Acid Signalling in Guard Cells. *Nature*, **406**: 731-734.
 25. Purev, M., Kim, Y. J., Kim, M. K., Pulla, R. K. and Yang, D. C. 2010. Isolation of a Novel Catalase (Cat1) Gene from *Panax ginseng* and Analysis of the Response of This Gene to Various Stresses. *Plant Physiol. Biochem.*, **48(6)**: 451-460.
 26. Rikin, A., Atsmon, D. and Gitler, C. 1979. Chilling Injury in Cotton (*Gossypium hirsutum* L.) Prevention by Abscisic Acid. *Plant Cell Physiol.*, **20(8)**: 1537-1546.
 27. Scandalios, J. G., Acevedo, A. and Ruzsa, S. 2000. Catalase Gene Expression in Response to Chronic High Temperature Stress in Maize. *Plant Sci.*, **156(1)**: 103-110.
 28. Sripinyowanich, S., Klomsakul, P., Boonburapong, B., Boonburapong, B., Bangyeekhun, T., Asami, T., Gu, H., Buaboocha, T. and Chadchawan, S. 2010. Exogenous ABA Induces Salt Tolerance in Indica Rice (*Oryza sativa* L.): The Role of *OsP5CS1* and *OsP5CR* Gene Expression during Salt Stress. *Environ. Exp. Bot.* DOI 10.1016/j.envexpbot.2010.01.009.
 29. Wan, X. R. and Li, L. 2006. Regulation of ABA Level and Water-stress Tolerance of *Arabidopsis* by Ectopic Expression of a Peanut 9-cis-epoxycarotenoid Dioxygenase Gene. *Biochem. Biophys. Res. Commun.*, **347(4)**: 1030-1038.



30. Wang, C. Y. 1991. Effect of Abscisic Acid on Chilling Injury of Zucchini Squash. *J. Plant Growth Regul.*, **10**: 101-105.
31. Wang, C. Y. and Buta, J. G. 1994. Methyl Jasmonate Reduces Chilling Injury in *Cucurbita pepo* through its Regulation of Abscisic Acid and Polyamine Levels. *Environ. Exp. Bot.*, **34**(4): 427-432.
32. Xie, F. X. 2000. *Practical Cultivating Technique of Chinese Herbal Medicine*. China Agriculture Press, Beijing, PP.57-61.
33. Xing, J. H. and Ding, Z. R. 1981. *Analytical Methods of Plant Biochemistry*. Science Press, Beijing, PP. 144-145.
34. Zhang Y., Zhu H., Zhang Q., Li M., Yan M., Wang R., Wang L., Welti R., Zhang W. and Wang X. 2009. Phospholipase α 1 and Phosphatidic Acid Regulate NADPH Oxidase Activity and Production of Reactive Oxygen Species in ABA-mediated Stomatal Closure in *Arabidopsis*. *Plant Cell*, **21**(8): 2357-2377.
35. Zhao, S. J. and Li, D. Q. 1999. *Experiment Guide of Modern Plant Physiology*. Science Press, Beijing, PP. 23-25.
36. Zhou, F. Q., Xu, L. C. and Zhang, Y. Q. 2002. The Shandong *Trichosanthes kirilowii* Production Situation Survey. *J. Shandong University Traditional Chinese Medicine*, **26**: 379-381.

اَبسيزيک اسيد تنش اکسایشی ناشی از سرما را در گیاهچه *Trichosanthes kirilowii* Maxim بهبود می بخشد

ج. ه. یاوو، پ. پ. گاوو، ی. پ. وانگ، ل. ه. وانگ، گ. د. ژو، پ. لیو

چکیده

گیاه *Trichosanthes kirilowii* که از گیاهان اقتصادی مهم در چین است به سرما حساس می باشد. به منظور بررسی اثر اَبسایسیک اسید (ABA) روی تحمل سرما در *Trichosanthes kirilowii* Maxim، غلظت های مختلفی از آن روی برگهای این گیاه پاشیده شد و سپس مقدار کاتالاز (CAT) سوپر اکسید دیسموتاز (SOD) و مالون دی الدهاید (MDA) در برگها اندازه گیری شد. نتایج نشان داد که در درجه حرارت 4 درجه سانتی گراد فعالیت کاتالاز و سوپر اکسید دیسموتاز نخست زیاد شد و بعد با افزایش غلظت ABA کاهش یافت. بر خلاف این، مقدار MDA ابتدا کم شد و سپس رو به فزونی گذاشت. همچنین، در تیمارهای 5 و هفت و نیم میلی گرم در لیتر ABA، هر دو آنها به حد بیشینه رسیدند. به منظور بررسی اثر اَبسایسیک اسید خارجی روی بیان ژن CAT در برگ *Trichosanthes kirilowii*، یک واکنش زنجیره ای پلیمرز همزمان (در زمان واقع) انجام شد. بر اساس نتایج، بیان نسبی ژن CAT در 4 درجه سانتی گراد همبستگی مثبت بالایی با فعالیت آنزیمی CAT و SOD نشان میداد ولی با مقدار MDA همبستگی منفی داشت. این یافته ها سه نتیجه گیری داشت. نخست اینکه اَبسایسیک اسید خارجی اثر معنی داری روی تحمل سرمای *Trichosanthes kirilowii* نشان می دهد. دوم آنکه اَبسایسیک اسید خارجی به طور معنی داری فعالیت آنزیمی CAT و SOD را در محیط سرد افزایش می دهد. نتیجه سوم اینکه در محیط سرد و تحت تاثیر ABA، بیان نسبی ژن کاتالاز 2 (CAT2) نقش مهمی در افزایش تحمل به سرما در برگ *Trichosanthes kirilowii* دارد.