IDENTIFICATION AND FUNCTIONAL ANALYSIS OF ABA-INSENSITIVE3 FROM ROSA CANINA

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Abstract

ABA-insensitive 3 (ABI3), initially identified in *Arabidopsis thaliana*, is intermediary in regulating ABA-responsive genes during seed dormancy inception and seed germination developmental program. In order to study whether the ortholog of *ABI3* from *Rosa canina* was functional, we isolated the ortholog by a combination of degenerate polymerase chain reaction (PCR) and rapid amplification of cDNA ends (RACE). It encodes 718 amino acids with a predicted molecular mass of 79.9kDa and a theoretical isoelectric point of 5.78. The predicted amino acid sequence of the RcABI3 is most closely related to the ABI3 orthologs identified in *Prunus avium* (PaABI3 and PaVP1). Expression analysis revealed that *RcABI3* was expressed in seeds and protocorm-like bodies (PLBs), but not in roots, stems, leaves and flowers. On a cellular level, we localization of PsABI3 in *Pisum sativum*. The *RcABI3* is able to restore the *Arabidopsis abi3-6* mutant seed dormancy ability and almost completely rescue the ABA sensitivity during seed germination, which suggest that it is a functional ABI3 ortholog. These results suggest that *RcABI3* is appropriate for application in genetic engineering strategies aimed at regulating seed dormancy and germination in *R. canina* or even in *Rosa* plants.

Introduction

Seed dormancy is an important component of plant fitness that causes a delay of germination until the arrival of a favorable growth season, but too deep dormancy will have a significant impact in practical application (Graeber *et al.*, 2012). *Rosa* plants are important ornamental plants widely used in the courtyard, flower bed and flower border around the world. Seed as an important introduction and conventional crossbreeding material for *Rosa* plants, the main obstacle is deep dormancy and low germination percentage (Jin *et al.*, 1993; Lu *et al.*, 2012). Therefore, we need new varieties that have shallow dormancy and high germination percentage. Study on the function of genes involving seed dormancy and germination will supply foundation for resolving this problem. However, there is no report about these genes in *Rosa* plants.

Abscisic acid (ABA) is a plant hormone that plays a significant role in the regulation of many physiological processes, especially in seed dormancy and germination (Nambara et al., 2010; Rehman et al., 2011; Tabur & Öney, 2012). ABI3 and VP1 are orthologous genes from Arabidopsis and maize respectively, and they encode transcription factor of B3 domain family (McCarty et al., 1991; Giraudat et al., 1992). ABI3/VP1 proteins act as intermediaries in regulating ABA-responsive genes during seed dormancy inception and seed germination developmental program (Giraudat et al., 1994; McCarty, 1995; Bonetta & McCourt, 1998; Zeng & Kermode, 2004). They specially expressed during zygotic embryogenesis (ZE) and somatic embryogenesis (SE) (Giraudat et al., 1992; Shiota et al., 1998; Ikeda-Iwai et al., 2002; Ikeda-Iwai et al., 2003; Suzuki et al., 2003).

All ABI3/VP1 proteins contain four conserved domains: an acidic activation domain A1 and the three basic domains, B1, B2, and B3 (McCarty *et al.*, 1991;

Giraudat *et al.*, 1992; Zeng & Kermode, 2004). A number of *ABI3/VP1* genes have been isolated from different species. Reports about the function of *ABI3* gene have been found in *Arabidopsis thaliana*, *Zea mays*, *Pisum sativum* and *Chamaecyparis nootkatensis* (Nambara *et al.*, 1994; Suzuki *et al.*, 2001; Lazarova *et al.*, 2002; Gagete *et al.*, 2009), but no in *Rosa* plants. Whether the *ABI3* gene from *Rosa* plants has the similar function or not, it needs study.

Rosa canina is an important medicinal plant (Chrubasik et al., 2008; Fujii & Saito, 2009; Kirkeskov et al., 2011; Tayefi-Nasrabadi et al., 2012), ornamental plant (Tian et al., 2008; Jiang et al., 2010) and rootstock for cut roses (Kroon & Zeilinga, 1974; Vries & Dubois, 1987). The problems in its seeds are just like those of most Rosa plants as mentioned above. Our study aims to isolate ABI3 gene from R. canina and to analyze its function. The seeds of Arabidopsis abi3-6 mutant are green at maturity, lack dormancy and germinated precociously (Nambara et al., 1994). It could be an excellent candidate for the functional analysis of ABI3 orthologous genes. Our analysis suggest that RcABI3 is able to restore the Arabidopsis abi3-6 mutant seed dormancy ability and almost completely rescue the ABA sensitivity during seed germination, which show that it is a functional ABI3 ortholog. It may be candidate gene to regulate seed dormancy and germination in R. canina or even in Rosa plants.

Materials and Methods

Plant material and growth conditions: Tissue culture seedlings of *R. canina* were maintained at $25 \pm 2^{\circ}$ C under a 16h light/8h dark photoperiods with a light intensity of 110 µmol m⁻² s⁻¹. Roots, stems and leaves were cut from tissue culture seedlings. Flowers and seeds were got from the *R. canina* planted in Research Garden of China Agricultural University. PLBs were one structure

developing from rhizoid tips through SE (Tian et al., 2008; Jiang et al., 2010), and were induced as described by Tian et al., (2008). All the samples were frozen immediately in liquid nitrogen and stored at -80°C for RNA extraction.

Seeds of A. thaliana were surface-sterilized, and planted on 1/2MS medium. To induce synchronous germination, all seeds were stratified at 4°C for 2 days in the dark and then transferred to a greenhouse at 21°C. with 16 light /8 h dark photoperiods.

RNA and DNA isolation, cloning and sequence analysis of RcABI3 gene: Total RNA was extracted from the seeds of R. canina using RN09-EASY spin Kit (Biomed, Beijing, China) according to the manufacturer's instructions. Total RNA preparations were subjected to an on-column DNase digestion to remove the genomic DNA contamination. The first strand cDNA was synthesized using superscriptII reverse transcriptase (Invitrogen, Beijing, China). Genomic DNA was isolated from young leaves using the NuClean PlantGen DNA Kit (ComWin, Beijing, China).

Primers used in this study were listed in Table 1. Nested polymerase chain reaction (PCR) was performed to obtain a partial sequence of RcABI3 by using the first strand cDNA of R. canina as a template. Two degenerate primers ABFS1 and ABRS1 were used for the first PCR, and then the ABRS1 primer and another primer ABFS2 were used for the second PCR. For 3'-rapid amplification of cDNA ends (RACE), two gene-specific primers, GSP1 and GSP2, were used. And the primers GSP3 and GSP4 were used for the 5'-RACE. The RACE reactions were performed with RACE cDNA amplification kit (Invitrogen, Beijing, China) according to the manufacturer's instruction. A full-length cDNA sequence was obtained by combining the 5'-RACE fragment, intermediate fragment and 3'-RACE fragment together. According to the sequences, a forward primer from the 5'-untranslated region (UTR) (F1) and a reverse primer from 3'-UTR (R1) of RcABI3 were designed to isolate the complete RcABI3 from both cDNA and genomic DNA. The amplification products were used to determine the sequences of the R. canina cDNA and genomic clone, and the positions of introns in the gene.

The sequence alignment of RcABI3 and other ABI3 sequences were compared by DNAMAN (version 6.0) and the phylogenetic tree was constructed by neighborjoining (NJ) method with MEGA program (version 4.0).

Semi-quantitative reverse transcription PCR (RT-PCR) assay: To investigate the expression of RcABI3 in R. canina, total RNA was extracted from various R. canina tissues and the first strand cDNA was synthesized as described above. The primers RTABIF and RTABIR were used to analyze the expression of RcABI3. The 18S rRNA gene (Genbank accession number: FM164424.1) was performed as a normalization control with primers 18SF and 18SR.

To confirm that the transgenic plants were expressing RcABI3 gene, total RNA was extracted from the leaves of abi3-6 mutant, lines transformed with empty vector and RcABI3, and the first strand cDNA was synthesized as described above. The expression level was checked using RcABI3 specific primer ABIF and ABIR. AtUBQ was used as a normalization control with primers AtUBQF and AtUBQR (Liang et al., 2010).

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Table 1. Primers used in this study.		
Primer name	Primer sequence (5'-3')	
ABFS1	TCCCTCCDCTCCCDGATTTCCCDTGCA	
ABRS1	ACYTTHACNCCHGCKATCADATATTT	
ABFS2	AAGCTGATTCTTGAGTGGGTTCAAAC	
GSP1	GAAGCCGAAACCCATCTTCCTGAGT	
GSP2	CCTGAGTTAGAGGCAAGGGACGGAA	
GSP3	CATACTGTTGTATCCCCGAGTCTTT	
GSP4	GAGATGGTTAGTTTGAACCCACTCA	
F1	ACCCACCATCCCCTATCTGATTCCA	
R1	TCCCACTTGCAGATAAAATCAAGGG	
GFPF	ACGAGCTCGATGGATGGAGTGCAAG	
GFPR	GACGTCGACCTGTTTCTTAGAT	
RTABIF	CAGCCTCACCGGCAATGATGCAAAC	
RTABIR	CCTTTGCGACTTTCCTGGCCTTTTG	
18SF	TGCCTAGCAGAACGACCCGAGAACA	
18SR	ATCCGTTGCCGAGAGTCGTTTAGAC	
OEABIF	AGGACCTAACAGAACTCGCCGTA	
OEABIR	CCGAATCGTTACGAGAGTAGTAATT	
AtUBQF	AACCCTTGAGGTTGAATCATC	
AtUBQR	GTCCTTCTTTCTGGTAAACGT	
ABIF	TAAGAAACAGTAAAGGAAGAAAGAA	
ABIR	CCTTTGCGACTTTCCTGGCCTTTTG	
$D=G/A/T \cdot K=0$	$TT \cdot H = A/T/C \cdot N = A/T/G/C$	

D=G/A/T; K=G/T; H=A/T/C; N=A/T/G/C

All RT-PCR experiments were repeated at least three times.

Subcellular localization: The RcABI3 open reading frame (ORF) were cloned into the SacI (GFPF) and SalI (GFPR) sites of the pSAT6-GFP-N1 vector. This vector contains a modified red-shifted green fluorescent protein (GFP) at NcoI-XbaI sites. The RcABI3 fusion products and a control GFP vector were respectively transformed into onion epidermal cells by particle bombardment as described previously (Wang & Fang, 2002). The transient expression of the fusion proteins and control vector were observed using confocal microscopy.

Generation of over-expression transgenic A. thaliana plants: The full-length RcABI3 cDNA sequence was amplified with primer OEABIF and OEABIR. The plasmid 35S::RcABI3 was made by ligating the ORF of RcABI3 into the binary vector pCAMBIA2300 using the BamHI and XbaI sites. The construct was transformed into A. thaliana abi3-6 mutant plants via Agrobacteriaum tumefaciens strain GV3101 by the floral-dip method (Clough & Bent, 1998). Desiccated mature seeds were harvested and the putative transformants were identified by growth on kanamycin medium. The transformants were verified as mentioned above. Phenotype of abi3-6, WT, and T3 homozygous transgenic generation seeds was photographed.

ABA sensitivity of seeds expressing the RcABI3 gene: Dry seeds of WT, over expression (OE)-1, OE-2 and OE-6, and immature seeds of abi3-6, empty vector were placed on 1/2MS agar plates containing no ABA or (±)-ABA at different concentrations (0.1-10µM) and then subjected to a 2d moist chilling. After 2d moist chilling, the seeds were transferred to germination conditions to monitor germination percentage. Germination percentage was recorded at day 4. The mark of seeds germination is radicle emergence. At least 100 seeds were used in each treatment, and triplicate treatments were carried out for each ABA concentration.

Isolation of *RcABI3* **gene from** *R. canina* **and sequence analysis:** To study the function of *ABI3* gene in *R. canina*, we isolated the *ABI3* ortholog from *R. canina* by 5'-and 3'-RACE PCR. As a result, we identified one *RcABI3* cDNA, designated as *RcABI3*. It was 2780bp containing an ORF of 2157bp and encoding a predicted protein of 718 amino acids (Fig. 1) with a predicted molecular mass of 79.9kDa, and a theoretical isoelectric point of 5.78.

The position of Fig. 1: Genomic fragment corresponding to *RcABI3* gene was isolated by PCR using F1 and R1. Comparison of the *RcABI3* cDNA to the genomic sequence revealed that this gene contained six introns, which was different from *AtABI3* which possessed five introns.

The predicted amino acid sequence of *RcABI3* was compared to other ABI3 proteins from *A. thaliana*, *Z. mays, Populus trichocarpa* cv. Trichobel and *Prunus avium* by DNAMAN (Fig. 2). The results showed that RcABI3 possessed all the four conserved domains including an acidic activation domain A1 and the three highly conserved basic regions, B1, B2 and B3. The A1 domain shared a much higher degree of homology with Zea may (Fig. 2). The RcABI3 displayed a higher degree of amino acid similarity in these four regions than over the entire protein region.

The position of Fig. 2: To investigate the evolutionary relationships among the predicted ABI3 proteins, a phylogenetic tree was constructed using ABI3 proteins from a taxonomically diverse set of species using the MEGA program (Fig. 3). The phylogenetic tree revealed that the putative RcABI3 was placed in one clade with PaABI3 and PaVP1. RcABI3 shares 45.3%, 29.7%, 51.6%, 51.6% with AtABI3, ZmVP1, PtABI3, PaABI3 proteins, respectively.

Tissue specificity of *RcAB13* **expression:** To gain a better understanding of the tissue specificity of *RcAB13* expression in *R. canina*, the expression profiles of *RcAB13* gene in various *R. canina* tissues were investigated using a semi-quantitative RT-PCR assay. Various tissues were respectively collected as described in materials and methods. *18S rRNA* gene expression was used as a control. *RcAB13* mRNA was detected in seeds and PLBs, but not in roots, stems, leaves and flowers (Fig. 4).

Localization of RcABI3: For analysis of the subcellular localization of RcABI3, a GFP fusion protein construct of RcABI3 driven by the constitutive Cauliflower Mosaic Virus 35S (CaMV 35S) promoter was introduced into onion epidermal cells by particle bombardment. Confocal microscopic examination showed that the RcABI3-GFP fusion protein was targeted into the nucleus, whereas the control GFP alone was distributed throughout the whole cell (Fig. 5). These results suggested that the RcABI3 protein was a nuclear localization protein.

Functional analysis of *RcABI3***:** To determine whether *RcABI3* is functionally conserved, the *RcABI3* ORF driven by the CaMV 35S promoter (*35S::RcABI3*) was expressed in the *Arabidopsis abi3-6* mutant background. The *RcABI3* expression level in transgenic lines was checked by PCR analysis using specific primers (Fig. 6A). Seeds derived

from *abi3-6* mutant and transformed with empty vector plants were green, had no dormancy and germinated precociously as described by Nambara *et al.*, (1994). However, seeds that expressed a functional *RcABI3* gene exhibited WT-like phenotype at maturity (yellow-brown) and obtained the dormancy ability (Fig. 6B). The seeds of *35S::RcABI3* transgenic lines did not germinate precociously, and could germinate after dormancy like WT. These results suggest that *RcABI3* is able to restore the *Arabidopsis abi3-6* mutant seed dormancy ability.

The position of Fig. 6: For studying the ABA sensitivity of seeds expressing RcABI3 gene, dry seeds of WT, OE-1, OE-2 and OE-6, and immature seeds of abi3-6, empty vector were treated as mentioned in materials and methods. All seeds on media with no ABA showed an equal capacity to germinate (96%-100%; Fig. 7). Seeds of the abi3-6 mutant and empty vector were highly insensitive to ABA and exhibited 96%-100% germination percentage at all of the ABA concentrations tested. However, seeds of WT plants and 35S::RcABI3 transgenic lines were all sensitive to ABA. Their germination was increasingly inhibited along with the rise of ABA concentration. When the ABA concentration rose up to 10µM, there was no seed germination for WT, and very little seed germination for transgenic lines (Fig. 7). And when the ABA concentration was 15µM, for transgenic lines, there was no seed germination (data not shown). These results suggest that The *RcABI3* almost completely rescue the ABA sensitivity during seed germination.

Discussion

ABA and gibberellin (GA) have essential and antagonistic roles in dormancy and germination. ABA promotes dormancy and inhibits germination, while GA is the opposite (Finkelstein *et al.*, 2008; Rehman *et al.*, 2011; Arefi *et al.*, 2012; Graeber *et al.*, 2012; Nadeem *et al.*, 2012). The seeds of *Rosa* plants are mostly in deep dormancy and difficult to germinate, and the high ABA concentration in the seed coat is considered to be the main reason (Lu *et al.*, 2012). To regulate their seed dormancy and germination, we should study function of genes responding to ABA during these two processes.

In this report, R. canina ortholog of ABI3 was isolated by a combination of degenerate PCR and RACE. Sequence analysis revealed that the deduced amino acids of RcABI3 gene contained all four regions that are typically conserved: A1, B1, B2 and B3 (Fig. 2). The same domains were also identified in the AtABI3 amino acid sequence (Giraudat et al., 1992). A phylogenetic tree based on amino acid sequences was constructed. It suggests that all the ABI3 proteins originated from the same ancestral origin, which subsequently diverged at different phases of evolution. RcABI3 is most closely related to PaABI3 and PaVP1 from P. avium (Fig. 3). Furthermore, subcellular localization analysis of RcABI3 revealed that it was present in the nucleus (Fig. 5). This is consistent with the previously identified nuclear localization of PsABI3 in P. sativum (Gagete et al., 2009). RcABI3 was expressed in seeds and PLBs, but not in roots, stems, leaves and flowers (Fig. 4), which was in agreement with the previous research that ABI3 specially expressed during ZE and SE (Rohde et al., 1998; Shiota et al., 1998; Lazarova et al., 2002).

1	cctgcttccttaatccgatacaccactctctccctcttgcacttatccgtacccaccatcccctatctgattccaacaaaaaaaccaaaa
91	ccattttttttggtgcgttttgataccATGGATGGAGTGCAAGTICAAGTCCACGGCAACCACCAAGATCTGCATGGAGAGGATCAC
1	M D G V Q V Q V H G N H H Q D L H G E D H
181	CACAGCCAGCATCTCGTCGGCAAAGAAGTGATGCGGAACGATTTCGGAGAAGAAGGTGACGCCGCAGATCTATGGCTTGATAATGAGCAA
22	H S Q H L V G K E V M R N D F G E E G D A A D L W L D N E Q
271	GATTCTCTTCTCGCTGACGTCAACGACGGAACTGCTTCCATCTTCTGCAATGACTTCCCTCGCCTGACTTCCCTTGCATGTCATCC
52	D S L L A D V N D G T A S I F C N D <u>F P P L P D F P C M S S</u>
361	TCTTCATCTTCATCTTCGTCTTCTTCCGCGGGGTTCCTGGGCGGTTCTCAAATCAGATGCGGAGGATAATAACAATTATCATTCT
82	<u>SSSSSSSSSSSSAASWAVLKSD</u> AEDNNNYHS
451 112	CAAGATTATCAGCAGCAACAAGAACAACAACAACTACTACTCTCGTAACGATTCGGCTGATGCACATCCGGCGGGGGGGG
541	ACCGCCTCGATGGAGATCTCTCAGCCGTCAGATCTCGGAATGGAGTGCATGGACATGATGGAGACTTTCGGGTACATAGATCTGTTCGAA
142	T A S M E I S Q P S D L G M E C M D M M E T F G Y I D L F E
631	GGCAACGAGTTGTTCGACCCGTCTTCCATTTTCCAAAACGAGAATCCAATGATGGACCAATTCCAAGCGCAGGAGCAACCTCCTCAGGAA
172	G N E L F D P S S I F Q N E N P M M D Q F Q A Q E Q P P Q E
721	CAGCTECATECAGACAATCAAACCTCACACCACAAGAGAACATGACCATEGGAGATCAGAGCAACAAGGTTCCEGGAEGACGACATEGCE
202	Q L H A D N Q T S H P Q E N M T M G D Q S N K V P E <u>D D M A</u>
811	TCTGTGTTCTTGGAGTGGCTGAGGTCAAACCGAGAGACGGTTTCAGCCGAGGATTTGAGGAGCGTGAAGATCAAGAAGTCAACAATCGAG
232	SVFLEWLRSNRETVSAEDLRSVKIKKSTIE
901	TCCGCCGCTAGGCGTTTGGGTGGAGGCAAGGAAGGAGGCGATGAAGCAGTTACTCAAACTGGTGCTTGAGTGGGTTCAAACTAACCATCTCCAA
262	S A A R R L G G G K E A M K Q L L K L V L E W V Q T N H L Q
991 292	AAGAGGCGCGGTACTAAAGACTCGGGGATACAACAGTATGCAGTAGACCCATTTCAAAACGCCATCCCTAACCCTAACCCTAGTCTTAAT
1081	CCTACACAAAATCCTCCCATAACATCGCCGTGGATGGCGTCTCCCCAGTATGATGCAGCGGCGCCCATTTTAGTCCCGACTCCATCTCAG
322	P T Q N P P I T S P W M A S P Q Y D A A A P I L V P T P S Q
1171	GTGGGTTATCCGTCAACTCCGATGATGGGGTTTATGGGTCAGGACCCTTTTGGAAACGGGCCGGGTTACCAGCAACCAATATCAGATCAA
352	V G Y P S T P M M G F M G Q D P F G N G P G Y Q Q P I S D Q
1261	TACCAGCATCAAATGCTAGAGACTGCACCAACCTGGCCGCCTTCATCTCCATTTATGGGCAACAATTATGGATCTTTCCCGGATAGTAAT
382	Y Q H Q M L E T A P T W P P S S P F M G N N Y G S F P D S N
1351	ATCCAACTAGCACCTCCTCAGCATCAGCAACCGCTTTCCGGTTACGGAGGGCAGTATGGTCAGTATCAATATTTTCAAGGGCAATCAGGT
412	I Q L A P P Q H Q Q P L S G Y G G Q Y G Q Y Q Y F Q G Q S G
1441	GAGCCGCAGCTGGTGAGGTTAGGGTCTTCGGCAACTAAAGAGGGCTAGGAAGAAGAGGAGGAGGAGGAGAGGAGGACTTTGTCACACCAC
442	E P <u>Q L V R L G S S A T K E A R K K R M Q R Q R R T L S H H</u>
1531	CATGGAAGGCATCATGGACACCAACAGAATCAGCATCCTAATCAAATGCCGGATCAAAGGCTAGTTGGGAACGCCGATCACAATTGCACT
472	H G R H H G H Q Q N Q H P N Q M P D Q R L V G N A D H N C T
1621	ACTGCCGCAATGGGCAATCCGGCTGCTTCTAACTGGTTTTATTGGCCCACCACGGCGGCTGGTGGTCCTGCTGCTGCAGCCTCACCGGCA
502	T A A M G N P A A S N W F Y W P T T A A G G P A P A A S P A
1711	ATGATGCAAACGATGGCTCCCGGGGCAGCACCATTGGTGCTTCCAGTTGATCGTCCGGCCAGTCAAGGGCAGAATTATAATCCGGGCCGG
532	M M Q T M A P G A A P L V L P V D R P A S Q G Q N Y N P G R
1801	ATTAATACACAGGAAAGGCGACAGGGATGGAGACCTGAGAATAAGAATTTGAGGTTCCTTCTTCAGAAAGTGTTGAAGCAAAGTGATGTG
562	INTQ <u>ERRQGWRPENKNLRFLLQKVLKQSDV</u>
1891	GGCAATCTTGGAAGAATTGTTTTGCCAAAAAAAGAAGCCGAAACCCATCTTCCTGAGTTAGAGGCAAGGGACGGAATTTCAATTGCGATG
592	GNLGRIVLPKKEAETHLPELEARDGISSIA
1981	GAAGACATCGGGACTTCTCGTGTATGGAACATGCGCTATAGGTACTGGCCCAACAACAAAGCAGGATGTATCTCCTTGAAAACACAGGA
622	<u>E D I G T S R V W N M R Y R Y W P N N K S R M Y L L E N T G</u>
2071	GATTTTGTGAGGGCAGATGGACTCCAAGAAGGGGACTTCATAGTCATCTATTCAGACGTCAAGTGTAACAAATATATGATAAGAGGAGTG
652	DFVRADGLQEGDFIVIYSDVKCNKYMIRGV
2161 682	AAGGTACGGCAAGCGGGGACTAAATCAGAGACCAAAAAGGCCAGGAAAGTCGCAAAGGAACCAACATGCAAGCACTCCATCTGGCAACAAT $\underline{K \ V \ R \ Q} \ A \ G \ T \ K \ S \ E \ T \ K \ R \ P \ G \ K \ S \ Q \ R \ N \ Q \ H \ A \ S \ T \ P \ S \ G \ N \ N$
2251	GGTICGTCATCTAAGAAACAGTAAaggaagaagaagaagaagaaggaggaaggaaggtgaattetteagagaaacceagetageteaace
712	G S S S K K Q *
2341 2431 2521 2611 2701	gcccttccggcaaagatggtctagggttgttggaatgcagagcagcccttgattttatctgcaagtgggaggggtttcagaattcatca tgcgtttttgaaagctgagatctggaggctggttggtgggaggtgatcactcagttgaagcatgcgcttggttttttgggtctcatttaa acgtatagagatctcccccaataccagtgtatgcagtctttgacattaagtatattagtgtatgttgtgttgttaattattaatgagtca tatatatgttgtagaattcaaaaaccataattcgtaaattatgtatatgggaattgaggggtcgataatgttcattca

Fig. 1. Nucleotide and deduced amino acid sequence of *RcABI3* (GenBank accession No. JX126487). The A1 domain is underlined in bold black line, and the B1, B2 and B3 domains are underlined in regular black lines.

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RcABI3 MDGVQVQVHGNHHQDLHGEDHHSQHLVGKEVMRNDFGEEGDAADLWLDNEQDSLLADVNDGTASIFCNT.FFFLP AtABI3 MKSLHVAANAGDLAEDCGILGGDADDTVLMDGIDEVGREIWLDDHGGDNNHVHGHQDDDLIVHHDPSTFYGT.LETLP ZmVP1 MKSLHVAANAGDLAEDCGILGGDADDTVLMDGIDEVGREIWLDDHGGDANHVHGHQDDDLIVHHDPSTFYGT.LETLP PtABI3 MKGLEMHGEDRHEGVENEGNPTIGFDAMEEE.QDILVEDK.EIWLERGQ.EDLLHASDVSTFHED.FFFLP PaABI3 MVHGLESSDVAFCGGDLHHHHMKDVNIPISDGFGGGGAMEELEDQEDNLGVDFS.EMWLDDNDQETAFLADVN.DPSTFYNHFFELP Consensus f d p lp	74 77 50 67 86
RcABI3 DFFCMSSSSSS SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS	141 149 90 157 168
RcABI3 TASMEISQFSDLGMECMDMMETFGYIDIFEGNELEDFSSIFQNENEMMDQFQAQEQPPQEQLHADNQTSH AtABI3 TASMEIFLDSSQFGCGEGGGCCIDMMETFGYMDLLDSNEFFDTSAIFSQDDDTQNPNLMDQTLERQEDQVVVEMMENN ZmVP1 SAGEGFDALDDIDQLLDBASLSMFWDSEFFPGVSMMLENAMSAPPQPVGDGMSEEKAVPEGTTGG PtABI3 TCSMEVPQPFDQAMELGIECMDVMEDGGYIDLLESNDFFDFSSIFHPDEGLFEEFQMEQNEPQDQLQLQVDEQAGN PaABI3 TASMEISQFSDLGREGG.AIDCMGAMETFGYTDLFESNEFFDLSSIFQSESLLMEQFQQDDHQQLLTPHQLQDFNEATAIIFQQQQQQ Consensus f	211 228 155 233 256
RcABI3 PQENNIMC DQSNKVPEDDMASY FLEWIRST FEVSAEDLR SVKIKKSTIPSAFRLGGGKEAMKQLLKIV EWVCTNHLCKRRS. AtABI3 SGGDMQMM NSSLEQ.DDDLAAV FLEWIKN KETVSAEDLR VKIKKATIPSAFRLGGGKEAMKQLLKIV EWVCTNHLGRRFT. ZmVP1 EEACH DASEGEELPRFEMEWITSK FENSAEDLR GIRLRRSTIPAAFARLGGGRCGTMQLLKIV EWVCTNHLGRRFT. PtABI3 EEITK.GKNDQEF DLQGGR.SDDLAMV FLEWIRSK FETVSAEDLR VKIKKSTIPCAFRLGGGREGKECKQLLKIV EWVCTNHLGRRF4. PABI3 EVAVRDEENNKKI DQNENKEFDDMAMVELEWIRSK FETVSAEDLR SVKIKKSTIPCAFRLGGGKEAMKQLLKIV EWVCTNHLCKRF5. Consensus f wl n e sa dlr tie aa rlggg qllkl l wvq hlq r	295 311 233 320 346
RcABI3 .TKDSGIQQYAVDFFQNAIFN PPSLNFTQNPFITSFWMASFQYDAAAFILVT TFSQVGYFS	367 375 302 397 431
RcABI3 FGNGPGYQQFISDQYQHQMLET.APTWPPSSP.FMGNNYGS PDS.NIQLAFFQHQQFISGYGGQYGQYQYFQGQS.GEFQIVRL AtABI3 NYPPQPEFLPLLES.PPSWPPPQ.SGPMPHQCPMPFTSQYNQFGDFTGFNGYNMNYQYFYVPAGQMRDQRLRL ZmVP1 FHQGPSTSSVVVNSQPFSPPPVGDMHGANMAWPQQYFFPPFGASTGSYFMPQPFSPGFGGQYAGAGAGHLSVAPQRMAGY PtABI3 FSNGSSNINGHPYGTPQCCNHMLQS.YQTWPPSQF.HSASHFNSFADN.NLQSAQFQNP.AFTGYG.NQYPYQYVPANGDNRLTRL PaABI3 YVNGPGPYQPSPEYHHMIDSGQFTWFSSPFGMGTAHYGSPDN.NIHLAFFPQHRFQAFAGYGSQYQFYQYFPGNGEH Consensus f	448 450 383 478 513
RcABI3 CSSATKEARKKRN CRORETLSHH HGRHHGHQQQNCHPNQMPDQRLVGNADHNCTTAAMGNFAASNEFYN PTTAAGGPAFAASPA AtABI3 CSSATKEARKKRN RRORFLSHH HRHNNNNNNNN CONCTQIGETCAAVAPQ.LNFVATTATG.GTMMYN PNVPAVPPQLPP ZmVP1 EASATKEARKKRN RRORFLSCLCQQRSQLSLGQIQTSVHLQEPSPRSTHSGPVTPSAGGRGFNSPSSQQQVQNPLSKS PtABI3 CSSATKEARKKRN RRORFLSYR RNQNHHNIGHQNQGAGDPHERLSDD.FNGAFTGQSNFGSVYN PTAAGGGSA PaABI3 CSSATKEARKKRN RRORFLSYH RHGHHHQQCHLNAGMPDHLLHQQHTRLVGNAANLNCANSVPLQANFGN FYN ATATAAPSPSPA Consensus satkearkkrm rgrr	531 531 462 552 600
RcABI3 MMQTMAFGAAFL.VLPVDRF7S.CGQNYNPGRINTCERRQCWRFENKNFFFLQKVLKQSDVCNLGRIVLFKKEAFTHLFELEARD AtABI3 VMETQLFTMDR7G.SASAMFR.QQVVEDRRQGWRFE.KNJFFLQKVLKQSDVCNLGRIVLFKKEAFTHLFELEARD ZmVP1 NSSRAFSSLEAAAAAPQTKFFFAGARQDDIHHRLAPAS.DKRQGAKAD.KNJFFLQKVLKQSDVCSLGRIVLFKKEAFTHLFELEARD PtABI3 STIVDAFVDRFM.QAQTNNH.RQAAFERRQGWKFE.KNJFFLQKVLKQSDVCSLGRIVLFKKEAFTHLFELEARD PaABI3 MMFSITFEAAFFFFVQQMDRFFSTQAQNYNQGRSAACERQERRQGWKSE.KNJFFLQKVLKQSDVCSLGRIVLFKKEAFTHLFELEARD Consensus p a	615 605 550 626 689
RcABI3 GISIAMEDIGTSRVWNMNYRYMWENNKSRMYLLENIG FYRADGLQEGDFIVIYSDYKONKYMIRGVKYC, AGTKSETKRPGK AtABI3 GISIAMEDIGTSRVWNMYRFMENNKSRMYLLENIG FYRADGLQEGDFIVIYSDYKOCKYLIRGVKYC, AGTKSETKRPGK ZmVP1 GISIAMEDIGTSRVWNMYRFMENNKSRMYLLENIG FYRSNPLQEGDFIVIYSDYKOCKYLIRGVKYR, PFAQEQGSGSSGGG PtABI3 GISIAMEDIGTSRVWNMYRFWENNKSRMYLLENIG FYRSNPLQEGDFIVIYSDYKOCKYLIRGVKVR, PFAQEQGSGSSGGG PtABI3 GISIAMEDIGTSRVWNMYRFWENNKSRMYLLENIG FYRTNGLQEGDFIVIYSDYKOCKYLIRGVKVR, PFAQEQGSKRAGK PaABI3 GISIAMEDIGTSRVWNMYRFWENNKSRMYLLENIG FYRTNGLQEGDFIVIYSDYKOCKYLIRGVKVR, AGFKFENKRAGK PaABI3 GISIFMEDIGTSRVWNMYRYWENNKSRMYLLENIG FYRANGLQEGDFIVIYSDYKOCKYLIRGVKVR, AGFKFENKRAGK PaABI3 GISIFMEDIGTSRVWNMYRYWENNKSRMYLLENIG FYRANGLQEGDFIVIYSDYKOCKYLIRGVKVR, AGFKFEGNKRPGK Consensus gis medigtsrvwnmyrywpnnksrmyllentg fv lqegdfiviysdvk ky irgvkvr	697 695 634 709 772
RCABI3 SCRNCHASTESGNN.GSSSKKQ AtABI3 SCRNINNNSESANVVVASPTSQTVK. ZmVP1 KHSPLCPAGERAAAAGAPEDAVVDGVSGACKGRSPEGVRRVRQQGAGAMSQMAV PtABI3 SCRNSHANGFAAANNGSGSQKQTVK. PaABI3 SCRNQHASTEAGTN.GSSPSSASASATHKKQ Consensus r	718 720 689 734 802

Fig. 2. The alignment of the identified RcABI3 with other ABI3/VP1 proteins. RcABI3, AtABI3 (*Arabidopsis thaliana* ABI3), ZmVP1 (*Zea mays* VP1), PtABI3 (*Populus trichocarpa* cv. Trichobel ABI3), PaABI3 (*Prunus avium* ABI3) were aligned. The four conserved domains correspond to the previously described: the acidic activation domain A1 (red) and the three highly conserved basic regions, B1 (blue), B2 (green) and B3 (brown).

A comparison of the RcABI3 cDNA sequence with its corresponding genomic DNA showed that this gene contained six introns within the RcABI3 ORF (data not shown), which indicated that the genomic DNA had not been conserved throughout evolution, as the RcABI3 gene in Arabidopsis contained five introns (Giraudat et al., 1992). Interestingly, over-expression of RcABI3 in Arabidopsis was able to restore the abi3-6 mutant seed dormancy ability and almost completely rescue the sensitivity to ABA during germination, despite having only 45.3% amino acid similarity to AtABI3 (Figs. 6 and 7). These results not only demonstrate that RcABI3 is a functional homologue of AtABI3, but also that the important structural regions of AtABI3 have also been conserved throughout evolution. These regions allow it to interact with other proteins in the ABA signal transduction pathway. The conservation of the ABI3 gene indicates the importance of the ABA signaling pathway during seed dormancy and germination.

Our results presented here suggest that *RcABI3* is appropriate for application in genetic engineering strategies aimed at regulating seed dormancy and germination in *R. canina or* even in *Rosa* plants through inducible antisense constructs in transgenic plants.



Fig. 3. Phylogenetic tree analysis of RcABI3 and other ABI3/VP1 proteins. The tree was constructed by neighborjoining (NJ) method with MEGA program. Branch numbers represent percentage of bootstrap values in 1000 sampling replicates and scale indicates branch lengths. The accession numbers are as follows: PaVP1 (P. avium VP1, AF411073.1), PaABI3 (P. avium ABI3, AF426832.1), PtABI3 (P. trichocarpa cv. Trichobel ABI3, AJ003166.1), McVP1 (Mesembryanthemum crystallinum VP1, AB015183.1), PsABI3 (Pisum sativum ABI3, AB080195.1), AtABI3 (A. thaliana ABI3, X68141.1), DcABI3 (Daucus carota ABI3, AB005558.1), SIABI3 (Solanum lycopersicum ABI3, NM 001247740.1), PabVP1 (Picea abies VP1, AF175576.1), ZmVP1 (Z. mays VP1, NM_001112070.1), FeVP1 (Fagopyrum esculentum VP1, AB099513.1), CnABI3 (Chamaecyparis nootkatensis ABI3, AJ131113.1), RcABI3(R. canina ABI3, JX126487).



Fig. 4. Expression patterns of *RcABI3* in different tissues. Expression patterns of *RcABI3* in roots, stems, leaves, flowers, seeds and PLBs. *18S rRNA* gene expression was used as a control. The data presented are typical of three independent experiments.



Fig. 5. Subcellular localization of RcABI3 in onion epidermal cells. Bright-field images (A and D), fluorescence images (B and E) and the merged images (C and F) of control and 35S::RcABI3-GFP fusion protein are shown.



Fig. 6. Phenotype of seeds expressing the *RcABI3* gene. A. The expression level of *RcABI3* in *abi3-6* mutant, lines transformed with empty vector and *RcABI3*. *AtUBQ* gene expression was used as a control. The data presented are typical of three independent experiments. B. Seeds of *abi3-6*, empty vector, WT and T3 generation of *35S::RcABI3* transgenic lines (OE-1, OE-2, OE-6). Bar=500µm.



Fig. 7. ABA sensitivity of seeds expressing the *RcABI3* gene. Dry seeds of WT, OE-1, OE2 and OE-6, and immature seeds of *abi3-6*, empty vector were placed on 1/2MS agar plates containing no ABA or (±)-ABA at different concentrations (0.1-10µM) and then subjected to a 2d moist chilling. After 2d moist chilling, the seeds were transferred to germination conditions to monitor germination percentage. The germination percentage was recorded at day 4. At least 100 seeds were used in each treatment, and triplicate treatments were carried out for each ABA concentration.

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References

- Arefi, I.H., S.K. Nejad and M. Kafi. 2012. Roles of duration and concentration of priming agents on dormancy breaking and germination of caper (*Capparis spinosa* L.) for the protection of arid degraded areas. *Pak. J. Bot.*, 44(SI2): 225-230.
- Bonetta, D. and P. McCourt. 1998. Genetic analysis of ABA signal transduction pathways. *Trends Plant Sci.*, 3(6): 231-235.
- Chrubasik, C., B.D. Roufogalis, U. Müller-Ladner and S. Chrubasik. 2008. A systematic review on the *Rosa canina* effect and efficacy profiles. *Phytother. Res.*, 22(6): 725-733.
- Clough, S.J. and A.F. Bent. 1998. Floral dip: a simplified method for Agrobacterium-mediated transformation of *Arabidopsis thaliana*. *Plant J.*, 16(6): 735-743.
- Finkelstein, R., W. Reeves, T. Ariizumi and C. Steber. 2008. Molecular aspects of seed dormancy. Annu. Rev. Plant Biol., 59(1): 387-415.

- Fujii, T. and M. Saito. 2009. Inhibitory effect of quercetin isolated from rose hip (*Rosa canina* L.) against melanogenesis by mouse melanoma cells. *Biosci.*, *Biotechnol.*, *Biochem.*, 73(9): 1989-1993.
- Gagete, A.P., M. Riera, L. Franco and M.I. Rodrigo. 2009. Functional analysis of the isoforms of an ABI3-like factor of *Pisum sativum* generated by alternative splicing. *J. Exp. Bot.*, 60(6): 1703-1714.
- Giraudat, J., B.M. Hauge, C. Valon, J. Smalle, F. Parcy and H.M. Goodmana. 1992. Isolation of the *Arabidopsis ABI3* gene by positional cloning. *Plant Cell*, 4: 1251-1261.
- Giraudat, J., F. Parcy, N. Bertauche, F. Gosti, J. Leung, P.C. Morris, M. Bouvier-Durand and N. Vartanian. 1994. Current advances in abscisic acid action and signalling. *Plant Mol. Biol.*, 26: 1557-1577.
- Graeber, K., K. Nakabayashi, E. Miatton, G. Leubner-Metzger and W.J.J. Soppe. 2012. Molecular mechanisms of seed dormancy. *Plant, Cell Environ.*, 35(10): 1769-1786.
- Ikeda-Iwai, M., M. Umehara, S. Satoh and H. Kamada. 2003. Stress-induced somatic embryogenesis in vegetative tissues of Arabidopsis thaliana. The Plant Journal, 34: 107-114.
- Ikeda-Iwai, M., S. Satoh and H. Kamada. 2002. Establishment of a reproducible tissue culture system for the induction of *Arabidopsis* somatic embryos. *J. Exp. Bot.*, 53(374): 1575-1580.
- Jiang, F.X., C.W. Tian, J.F. Zhang, N. Ma, C.Q. Zhang and L.J. Zhao. 2010. Microscopic observations on development of protocorm-like body of *Rosa canina* L. *Plant Physiol. Commun.*, 46(6): 589-596.

- Jin, B., H.R. Dong and X.H. Yang. 1993. Dormancy of seeds of *Rosa hybrida* caused by abscisic acid. *Acta Horticulturae Sin*, 20(1): 86-90.
- Kirkeskov, B., R. Christensen, S. Bügel, H. Bliddal, B. Danneskiold-Samsøe, L.P. Christensen and J.R. Andersen. 2011. The effects of rose hip (*Rosa canina*) on plasma antioxidative activity and C-reactive protein in patients with rheumatoid arthritis and normal controls: a prospective cohort study. *Phytomedicine*, 18(11): 953-958.
- Kroon, G.H. and A.E. Zeilinga. 1974. Apomixis and heterogamy in rose rootstocks. *Euphytica*, 23: 345-352.
- Lazarova, G., Y. Zeng and A.R. Kermode. 2002. Cloning and expression of an Abscisic acid Insensitive 3 (ABI3) gene homologue of yellow-cedar (Chamaecyparis nootkatensis). J. Exp. Biol., 53(371): 1219-1221.
- Liang, J.L., L.J. Zhao, R. Challis and O. Leyser. 2010. Strigolactone regulation of shoot branching in chrysanthemum (*Dendranthema grandiflorum*). J. Exp. Bot., 61(11): 3069-3078.
- Lu, Y., Y. Zhou, R. Chen, R. Chu and H.Y. Zhou. 2012. Research status and suggestions on seed propagation of *Rosa* L. plants. *Seed*, 31(1): 60-62.
- McCarty, D.R. 1995. Genetic control and integration of maturation and germination pathways in seed development. *Ann. Rev. Plant Physiol. Plant Mol. Biol.*, 46: 71-93.
- McCarty, D.R., T. Hattori, C.B. Carson, V. Vasil, M. Lazar and I.K. Vasil. 1991. The *Viviparous-1* developmental gene of maize encodes a novel transcriptional activator. *Cell*, 66(5): 895-905.
- Nadeem, M., F. AI-Qurainy, S. Khan, M. Tarroum and M. Ashraf. 2012. Effect of some chemical treatments on seed germination and dormancy breaking in an important medicinal plant *Ochradenus arabicus* Chaudhary, Hill c. & A.G. Mill. *Pak. J. Bot.*, 44(3): 1037-1340.
- Nambara, E., K. Keith, P. McCourt and S. Naito. 1994. Isolation of an internal deletion mutant of the Arabidopsis thaliana ABI3 gene. Plant Cell Physiol., 35(3): 509-513.
- Nambara, E., M. Okamoto, K. Tatematsu, R. Yano, M. Seo and Y. Kamiya. 2010. Abscisic acid and the control of seed dormancy and germination. *Seed Sci. Res.*, 20: 55-67.

- Rehman, S., H.R. Choi, M. Jamil and S.J. Yun. 2011. Effect of GA and ABA on germination behavior of black raspberry (*Rubus coreanus* Miquel) seeds. *Pak. J. Bot.*, 43(6): 2811-2816.
- Rohde, A., W. Ardiles-Diaz, M.V. Montagu and W. Boerjan. 1998. Isolation and expression analysis of an *Abscisic Acid-Insensitive 3 (ABI3)* homologue from *Populus trichocarpa*. *J. Exp. Bot.*, 49(323): 1059-1060.
- Shiota, H., R. Satoh, K. Watabe, H. Harada and H. Kamada. 1998. C-ABI3, the carrot homologue of the Arabidopsis ABI3, is expressed during both zygotic and somatic embryogenesis and functions in the regulation of embryospecific ABA-inducible genes. Plant Cell Physiol., 39(11): 1184-1193.
- Suzuki, M., C.Y. Kao, S. Cocciolone and D.R. McCarty. 2001. Maize VP1 complements *Arabidopsis abi3* and confers a novel ABA/auxin interaction in roots. *Plant J.*, 28(4): 409-418.
- Suzuki, M., M.G. Ketterling, Q.B. Li and D.R. McCarty. 2003. Viviparous1 alters global gene expression patterns through regulation of abscisic acid signaling. *Plant Physiol.*, 132(3): 1664-1677.
- Tabur, S. and S. Öney. 2012. Comparison of cytogenetic antagonism between abscisic acid and plant growth regulators. *Pak. J. Bot.*, 44(5): 1581-1586.
- Tayefi-Nasrabadi, H., S. Sadigh-Eteghad and Z. Aghdam. 2012. The effects of the hydroalcohol extract of *Rosa canina* L. fruit on experimentally nephrolithiasic wistar rats. *Phytother. Res.*, 26(1): 78-85.
- Tian, C.W., Y. Chen, X.L. Zhao and L.J. Zhao. 2008. Plant regeneration through protocorm-like bodies induced from rhizoids using leaf explants of *Rosa spp. Plant Cell Rep.*, 27(5): 823-831.
- Vries, D.P.D. and L.A.M. Dubois. 1987. Variation for plant characters and for performance of softwood cuttings of *Rosa canina* 'Inermis' seedlings. *Euphytica*, 36: 407-412.
- Wang, G.L. and H.Y. Fang. 2002. Plant gene engineering. (2nd Ed) Science Press, Beijing.
- Zeng, Y. and A.R. Kermode. 2004. A gymnosperm *ABI3* gene functions in a severe abscisic acid-insensitive mutant of *Arabidopsis* (*abi3-6*) to restore the wild-type phenotype and demonstrates a strong synergistic effect with sugar in the inhibition of post-germinative growth. *Plant Mol. Biol.*, 56: 731-746.

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