Molecular characterization of \textit{HbEREBP2}, a jasmonate-responsive transcription factor from \textit{Hevea brasiliensis} Muell. Arg.

Yue-Yi Chen$^{1,2}$, Li-Feng Wang$^1$, Shu-Guang Yang$^1$, Wei-Min Tian$^1$*

$^1$Ministry of Agriculture Key Laboratory for Rubber Biology, Rubber Research Institute, Chinese Academy of Tropical Agricultural Sciences, Danzhou, Hainan 571737, China.

$^2$College of Horticulture and Landscape Architecture, Hainan University, Danzhou, Hainan 571737 China.

Accepted 8 July, 2011

Transcription factors of AP2/ERF superfamily are generally involved in defense responses of plants to biotic and abiotic stresses. Although, defense proteins are present in abundance in laticifers of rubber tree, little is known about their transcriptional regulation. In this study, a full length cDNA, referred to as \textit{HbEREBP2} was characterized by means of bioinformatic analysis and quantitative real-time RT-PCR. The \textit{HbEREBP2} was 786-bp in length and contained a 480-bp open reading frame (ORF) encoding a protein of 159 amino acid residues. Bioinformatic analysis showed that the deduced amino acid sequence of \textit{HbEREBP2} had a specific domain of AP2 superfamily and shared relative high identity with members of CBF/DREB subfamily from different plant species. Quantitative real-time RT-PCR revealed that methyl jasmonate was more effective than ethylene and rapidly than mechanical wounding on up-regulating \textit{HbEREBP2} expression. The results suggest that \textit{HbEREBP2} may be involved in the regulation of jasmonate-mediated defense responses in laticifers of rubber tree.

Key words: \textit{Hevea brasiliensis}, Laticifer, defense proteins, AP2/ERF transcription factor, Methyl jasmonates, Ethephon, mechanical wounding.

INTRODUCTION

AP2/ERF transcription factors are characterized by a 60 to 70 amino acid DNA-binding domain specifically binding to GCC box or GCC-like box in the ethylene-responsive genes (Jofuku et al., 1994; Ohme-Takagi and Shinshi, 1995). This domain is first identified in APETALA2 (AP2) from the Arabidopsis (\textit{Arabidopsis thaliana}) and in the ethylene-responsive element binding proteins (EREBPs) from tobacco (\textit{Nicotiana tabacum}). The EREBP\textsubscript{s} are currently renamed ERF\textsubscript{s} (Nakano et al., 2006). The AP2/ERF superfamily contains three families, ERF, AP2 and RAV (Nakano et al., 2006). The ERF family possesses only one AP2 domain and is further divided into two major subfamilies, the ERF subfamily and the CBF/DREB subfamily (Nakano et al., 2006). The ERF binding \textit{cis}-element is referred as the GCC box, which is found in the promoters of several PR (Pathogenesis-related) genes and confers ethylene responsiveness (Ohme-Takagi and Shinshi, 1995). The DREB binding \textit{cis}-element is called C-repeat (CRT)/ dehydration-responsive element (DRE) (similar to GCC box), which is involved in the regulation of the expression of dehydration- and low-temperature-responsive genes (Singh et al., 2002).

Based on the characteristic structure of DREB transcription factors, the CBF/DREB subfamily is further divided into six groups from A-1 to A-6 (Sakuma et al., 2002; Nakano et al., 2006). Members of AP2/ERF superfamily play important roles in regulating...
appropriate defense responses of plants against pathogens and herbivores (Kimura et al., 2011; Leon-Reyes et al., 2010).

Laticifers in rubber tree are the sole site for natural rubber biosynthesis and storage. They are also considered as a kind of defense structure for the presence of abundance of defense proteins, hevein, chitinase and siderophore (van Parijis et al., 1991; Gidrol et al., 1994; Subroto et al., 1996). In the practice of natural rubber production, latex is exploited from laticifers by tapping which results in a repeatedly mechanical wounding and latex flow of rubber tree. Meanwhile, ethephon, an ethylene releaser, is found to be effective on increasing rubber yield and thus commonly applied in rubber plantation since 1970s (Coupe and Chrestin, 1989). It is well known that either tapping or ethephon application increases the level of defense proteins in laticifers (Kush et al., 1990). These defense-related proteins are suggested to act as a biochemical barrier at the end of severed laticifers (Hao et al., 2004). To elucidate the transcriptional regulation of the defense proteins, this study focused on the molecular characterization of a member of AP2/ERF transcription factors from laticifers of rubber tree.

**MATERIALS AND METHODS**

**Plant material and treatments**

7-year-old virgin trees of rubber tree clone CATAS 7-33-97 were planted at the Experimental Farm of the Chinese Academy of Tropical Agricultural Sciences on Hainan Island of P.R. China. The trees were treated with mechanical wounding (cut the trunk barks in a half spiral pattern without latex flow) or tapping (cut the trunk barks in a half spiral pattern with latex flow) while epicormic shoots were treated with 0.5% ethephon or 0.1% methyl jasmonate. Latex samples from every three of either wounded virgin trees or tapped virgin trees for each interval were collected by cutting at 2 h, 6 h, 1 d, 3 d, 5 d, and 7 d after treatments. As control, latex samples were collected from every three of virgin trees without any treatments at the corresponding intervals. The latex samples from three of either wounded virgin trees or tapped virgin trees for each interval were collected by cutting at 2 h, 6 h, 1 d, 3 d, 5 d, and 7 d after treatments. As control, latex samples were collected from three of epicormic shoots respectively treated with water (the solvent of ethephon) and 6% ethanol (the solvent of methyl jasmonate) at the corresponding intervals.

**Isolation of total RNA**

Total RNA was extracted from latex according to the method (Tang et al. 2007; Xiao et al. 2009). The quality and concentration of the extracted RNA were checked by agarose gel electrophoresis and measured by a spectrophotometer (Genespec 2100 pro UV/Visible Spectrophotometer, USA).

**Full length cDNA cloning**

A 704-bp fragment (GenBank Accession No.: EC 607860) with conserved domain of EREBP was isolated from latex EST database of rubber tree clone RRIM600 (http://genome.ukm.my/nrestdb). In order to obtain the full length cDNA from rubber tree clone CATAS 7-33-97, primers were designed for RACE and PCR (Table 1). The 3'-ready cDNA was synthesized by reversely transcribing 1 μg total RNA with oligo dT-3 site adaptor primer (5'-CCA GTG AGC AGA GTG ACG-3') and the specific primer primer 3HbEREBP1 based on the blasted EST sequence, respectively. The first round of 3'-RACE was performed using the universal primer (5'-CCA GTG AGC AGA AGT AGG ACT CGA GCT CAA GCT TTT TTT TTT TT-3') supplied by 3'-RACE kit (Takara, Dalian, China). The specific primers for 3'-RACE were designed as primer 3HbEREBP1 and the nested primer HbEREPB2 based on the blasted EST sequence, respectively. The first round of 3'-RACE was performed using the universal primer (5'-CCA GTG AGC AGA AGT AGG ACT CGA GCT CAA GCT TTT TTT TTT TT-3') and the specific primer HbEREBP1 in a total volume of 50 µL under the conditions of 94°C for 5 min, 55°C for 5 min, 72°C for 40 min followed by 31 cycles of amplification (94°C for 1 min, 55°C for 1 min, 72°C for 1 min). The PCR product was ten-fold diluted as a template for the second round of 3'-RACE using the universal primer (5'-GAG GAC TCG AGC TCA AGC-3') and the specific primer 3HbEREBP2 under the same conditions as the first round 3'RACE. The products were purified and cloned into pGEM-T easy vector, followed by sequencing. After alignment and assembly of the sequences of the blasted EST sequence and the 3'-RACE products, the full-length cDNA sequence were deduced and subsequently obtained by PCR. Its open reading frame (ORF) was amplified by RT-PCR using primers HbEREPF and HbEREBPR with the PCR kit (Takara, Dalian, China) under the conditions of 94°C for 5 min, followed by 32 cycles of amplification (94°C for 1 min, 55°C for 1 min, 72°C for 2 min). The products were purified and cloned into pGEM-T easy vector (Promega, Fitchburg, Wisconsin, USA), and sequenced.

**Multiple alignments and bioinformatics analyses**

The full-length cDNA sequence was compared to the non-redundant peptide database at the National Centre for Biotechnology Information (NCBI) (http://www.ncbi.nlm.nih.gov) using Basic Local Alignment Search Tool (BLAST) version 2.2.17 and DNAMAN version 6.0. The cis-acting elements in the promoters of defense proteins were analyzed online using Plantcare (http://bioinformatics.psb.ugent.be/webtools/plantcare/html/).

**Real-time RT-PCR**

Prior to cDNA synthesis, RNA samples were treated with Ambion...
the practice of natural rubber production, people regularly cut the trunk bark of rubber tree, normally with a two-day interval, for the purpose of latex exploitation. This action is called tapping which resulted in repeatedly mechanical wounding and latex flow of rubber tree. The level of HbEREBP2 expression was flat and low in virgin trees without any treatments (Figure 3). There was no significant difference in the level of HbEREBP2 expression within 1 d upon treatment with either tapping or mechanical wounding while the expression of HbEREBP2 was significantly up-regulated at 3 d and remained relatively high level within 7 d after the treatments (Figure 3). The expression pattern of HbEREBP2 was similar between the treatment with tapping and the treatment with mechanical wounding (Figure 3), indicating that latex flow had little effect on up-regulating HbEREBP2 expression.

**Effect of methyl jasmonate and ethephon on the expression of HbEREBP2**

HbEREBP2 expression was rapidly and strongly up-regulated by methyl jasmonate, which was in contrast to the effect of tapping and mechanical wounding. The expression of HbEREBP2 was up-regulated more than two times at 2 h and four times at 6 h and thereby returned to the level of control after treatment with methyl jasmonate (Figure 4). The range of up-regulated expression of HbEREBP2 was much lower upon ethephon than that upon methyl jasmonate (Figure 4).

**DISCUSSION**

62 CBF/DREB members have been identified in Arabidopsis and are divided into six groups, namely A1-A6 (Nakano et al., 2006). The members of group A5 were further divided into subgroup IIa, IIb, and IIc. Of which IIa is characterized by one AP2/ERF domain and an ethylene-responsive element binding factor-associated amphiphilic repression (EAR) motif D(L/M)NxxP, IIb is characterized by one AP2/ERF domain and a LWSY motif while IIc is characterized by one AP2/ERF domain and a ethylene-responsive element binding factor-associated amphiphilic repression motif. This discrepancy may be mainly ascribed to the difference in criteria between phylogenetic tree analysis, however, clustered HbEREBP2 into subgroup IIb other than IIc although, it had no LWSY motif. This discrepancy may be mainly ascribed to the difference in criteria between phylogenetic tree analysis and classification of the subgroups. Members of the three subgroups of group A5 are generally involved in the regulation of responses of plants to biotic and abiotic stresses and several members of subgroup IIb mediated the salicylic acid (SA)-, jasmonate- and ethylene-dependent responses (Table 2). There are several defense proteins in abundance in lutoids, a kind of

**RESULTS**

**Isolation and characterization of HbEREBP2**

A 704-bp fragment (GenBank Accession No.: EC607860) from rubber tree clone RRIM 600 was found in latex EST library which showed similarity to some extent with the EREBP genes from Arabidopsis as revealed by a BlastX search. The start codon ATG was found in this EST. In this study, a homologous fragment was amplified and cloned from rubber tree clone CATAS7-33-97. It was identical with the EST. 3’-RACE generated a 328-bp fragment with the primers 3HbEREBP1 and 3HbEREBP2 (Table 1). By alignment and assembly of these two fragments, a full-length cDNA was deduced. The cDNA, referred to as HbEREBP2 (GenBank accession number: HQ171931), was 786-bp in length and contained a 480-bp ORF encoding a putative protein of 159 amino acids, flanked by a 192-bp 5’-UTR (untranslated region) and a 144-bp 3’-UTR. The predicted molecular mass of the putative protein, HbEREBP2, is 17.7 kDa with a pI of 9.71. The deduced amino acid sequence of HbEREBP2 had specific domain of AP2 superfamily, sharing 62.11, 60.87, 37.74, 37.69, 34.18 and 28.51% identity with PtAP2, RcTINY, BpDREB, GmDREB3, AtERF018 andMdAP2, respectively (Figure 1). Phylogenetic tree analysis clustered HbEREBP2 into DREB A5 IIb subgroup although, it had no LWSY motif (Figures 1 and 2).

**Effect of tapping and mechanical wounding on the expression of HbEREBP2**

In the practice of natural rubber production, people

DNA-free Dnase treatment and Removal reagents to remove the contaminating genome DNA. First strand cDNA was synthesized from 2 µg of RNA with M-MuLV reverse transcriptase and random hexamer primers (Takara, Dalian, China) according to the manufacturer’s instructions. The cDNA was diluted 1:20 with nuclease-free water. Aliquots of the same cDNA sample were used for real-time PCR with primers YEREBPF/YEREBPR designed for HbEREBP2, and Y18Sr for 18S rRNA (as a house-keeping gene) (Table 1). Reactions were performed in a 25 µL volume containing 500 nM of each primer and 1×SYBER Green PCR master mix (Takara, Dalian, China). The primers for 18S rRNA was used at the concentration of 50 nM.

Real-time RT-PCR was performed using the fluorescent dye SYBR-Green (Takara, Dalian, China) and the LightCycler 2.0 system (Roche Diagnostics, Germany). The reactions were carried out as follows: 30 s at 95°C for denaturation, 5 s at 94°C, 20 s at 60°C, and 20 s at 72°C for amplification. The relative abundance of transcripts was calculated according to the LightCycler Relative Quantification Software 4.05 instructions. The specificity of each primer pairs was verified by determining the melting curves at the end of each run and by sequencing the amplified fragments from agarose gel electrophoresis. The statistical significance of the values was determined by the t-test. The P values 0.05 and 0.01 were respectively considered to be significant and very significant in all cases.
Figure 1. Amino acid alignment of HbEREBP2 protein and other AP2/ERF proteins. The identical amino acids were marked with asterisk and the well-conserved residues were marked with dot. The conserved domain and motif was underlined. The aligned HbEREBP2 protein was from Hevea brasiliensis (GenBank Accession No.: HQ171931) and AP2/ERF proteins were from Arabidopsis thaliana, AtERF018 (GenBank Accession No.: Q9S7L5.1); Populus trichocarpa, PtAP2 (GenBank Accession No.: ABO62999.1); Ricinus communis, RctINY (GenBank Accession No.: EEF46236.1); Malus domestica, MdAP2 (GenBank Accession No.: ADE41099.1); Broussonetia papyrifera, BpDREB (GenBank Accession No.: ABU84809.1); and Glycine max, GmDREB3 (GenBank Accession No.: ABB36646.1), respectively.

organelle in laticifer cells. The accumulation of these proteins released from the broken lutoids at the end of the severed laticifers after tapping is believed to act as a biochemical barrier against pathogen and herbivore...
Figure 2. Phylogenetic tree of HbEREBP2 from rubber tree and members of ERF family from Arabidopsis.
attacks (Hao et al., 2004). The phytohormones salicylic acid (SA), jasmonic acid (JA), and ethylene (ET) are of the most important players in regulating the induced defense responses that are differentially effective against specific types of attackers (Leon-Reyes et al., 2009). In general, SA is active against biotrophic pathogens while
Table 2. Members of subgroup A5 with identified functions in arabidopsis.

<table>
<thead>
<tr>
<th>Type</th>
<th>TAIR number</th>
<th>Gene name</th>
<th>Function</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5 IIa</td>
<td>At1g46768</td>
<td>RAP2.1</td>
<td>Involved in response to drought and cold stress via an ABA-independent pathway.</td>
<td>(Dong and Liu, 2010)</td>
</tr>
<tr>
<td>A5 IIa</td>
<td>At4g06746</td>
<td>RAP2.9</td>
<td>Involved in response to both pathogen infection and cold treatment.</td>
<td>(Tsutsui et al., 2009)</td>
</tr>
<tr>
<td>A5 IIa</td>
<td>At2g23340</td>
<td>DEAR3</td>
<td>Involved in response to both pathogen infection and cold treatment.</td>
<td>(Tsutsui et al., 2009)</td>
</tr>
<tr>
<td>A5 IIa</td>
<td>At4g36900</td>
<td>RAP2.10/DE AR4</td>
<td>Enhanced tolerance to photoinhibitory light and exogenous H2O2, increased expression of antioxidative genes.</td>
<td>(Welling and Palva, 2008; Rossel et al., 2007)</td>
</tr>
<tr>
<td>A5 IIa</td>
<td>At5g67190</td>
<td>DEAR2</td>
<td>Involved in defence responses to bacterial pathogens between Arabidopsis thaliana and Pseudomonas syringae; salt, osmotic, and cold stress.</td>
<td>(Truman et al. 2006; Kreps et al., 2002)</td>
</tr>
<tr>
<td>A5 IIa</td>
<td>At3g50260</td>
<td>DEAR1</td>
<td>Involved in response to salt, osmotic, and cold stress; cooperatively regulated by ethylene and jasmonate; functionally redundant roles in aspects of development in addition to flowering time.</td>
<td>(Kreps et al., 2002; Veley and Michaels, 2008)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At1g21910</td>
<td>DREB26</td>
<td>Involved in plant developmental processes as well as biotic and/or abiotic stress signaling.</td>
<td>(Krishnaswamy et al., 2011)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At1g77640</td>
<td>T5M16.23</td>
<td>Involved in salt stress pathways.</td>
<td>(Lee et al., 2007; Ma et al., 2006)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At1g44830</td>
<td>T12C22.10</td>
<td>Involved in MAP kinase 4 regulated salicylic acid- and jasmonic acid/ethylene-dependent responses.</td>
<td>(Brodersen et al., 2006)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At4g31060</td>
<td>F6i18.30</td>
<td>Involved in jasmonate-mediated activation.</td>
<td>(Brown et al., 2003)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At5g21960</td>
<td></td>
<td>Involved in the epigenetic regulation of pollen tube growth and fertilization.</td>
<td>(Cartagena et al., 2008)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At1g19210</td>
<td>T29M8.8</td>
<td>Involved in light regulation of development.</td>
<td>(Lee et al., 2007)</td>
</tr>
<tr>
<td>A5 IIb</td>
<td>At1g74930</td>
<td>ORA47</td>
<td>Involved in impacting pathogen response and cell cycle during geminivirus infection; jasmonate-mediated transcriptional reprogramming of metabolism.</td>
<td>(Ascencio-Ibanez et al., 2008; Pauwels et al., 2008)</td>
</tr>
<tr>
<td>A5 IIc</td>
<td>At1g22810</td>
<td>T22J18.2</td>
<td>Involved in salt stress pathways; 12-oxo-phytodienoic acid triggers expression of a distinct set of genes and plays a role in wound-Induced gene expression in arabidopsis.</td>
<td>(Ma et al., 2006; Taki et al., 2005)</td>
</tr>
<tr>
<td>A5 IIc</td>
<td>At1g71520</td>
<td>F26A9.11</td>
<td>Involved in atrazine toxicity and sucrose-induced tolerance.</td>
<td>(Ramel et al., 2007)</td>
</tr>
</tbody>
</table>
JA is effective against necrotrophs and insect herbivores (Grant and Lamb, 2006). SA signaling act antagonistically on JA-dependent defenses in a nonexpressed pathogen related 1 (NPR1)-dependent manner (Spoel et al., 2003) while ethylene is involved in the regulation of the crosstalk between these two signalings (El Oirdi et al., 2011). The expression of genes encoding for the defense proteins, such as hevein, chitinase and β-1,3-glucanase is up-regulated by mechanical wounding and the application of methyl jasmonate (Yang et al., 2008). Meanwhile, the application of ethephon increases the level of defense-related proteins in laticifers (Kush et al., 1990). These data suggest that jasmonate signaling and ethylene signaling act synergistically in positively regulating the defense proteins in laticifer cells of rubber tree. In this study, however, ethephon has less effect than methyl jasmonate on up-regulating the expression of HbEREBP2, suggesting that HbEREBP2 may be involved in the transcriptional regulation of jasmonate-mediated defense responses which are effective against necrotrophs and insect herbivores at the end of the severed laticifers. It is interesting that both the GCC box and the CRT/DRE which are respectively characterized as the ERF and DREB binding cis-elements in ethylene-responsive genes (Ohme-Takagi and Shinihsi, 1995) and dehydration- and low-temperature-responsive genes (Singh et al., 2002) are not found in the available promoter sequences of genes encoding for hevein and β-1,3-glucanase by online analysis with plant care. Whether the HbEREBP2 is involved in transcriptionally regulating on the defense proteins remains to be elucidated in rubber tree.

ACKNOWLEDGEMENTS

This work is supported by the earmarked fund for China Agriculture Research System (CARS-34-GW1), Chinese National Nonprofit Institute Research Grant of CATAS-RRI (XJSYWFZX2009-09).

REFERENCES


induced tolerance. BMC Genomics, 8: p. 450.