

A Universal Primer for Isolation of Fragments of a Gene Encoding Phytoene Desaturase for Use in Virus-Induced Gene Silencing (VIGS) Studies

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Abstract

We have been using Virus-Induced Gene Silencing (VIGS) to test the function of genes that are candidates for involvement in floral senescence. Although VIGS is a powerful tool for assaying the effects of gene silencing in plants, relatively few taxa have been studied using this approach, and most that have are in the *Solanaceae*. We typically use silencing of phytoene desaturase (*PDS*) in preliminary tests of the feasibility of using VIGS. Silencing this gene, whose product is involved in carotene biosynthesis, results in a characteristic photobleaching phenotype in the leaves. We have found that efficient silencing requires the use of fragments that are more than 90% homologous to the target gene. To simplify testing the effectiveness of VIGS in a range of species, we designed a set of universal primers to a region of the *PDS* gene that is highly conserved among species, and that therefore allows an investigator to isolate a fragment of the homologous *PDS* gene from the species of interest. We report the sequences of these primers and the results of VIGS experiments in horticultural species from the *Asteraceae*, *Leguminosae*, *Balsaminaceae* and *Solanaceae*.

INTRODUCTION

Virus-induced gene silencing (VIGS) is a method of transiently interrupting gene function through RNA interference. The VIGS process is a natural plant defense mechanism and is initiated experimentally by *Agrobacterium*-mediated introduction of viral genomes containing a fragment of a targeted plant gene. When the virus replicates and spreads in the infected plants, the plant cells recognize the foreign double-stranded chimeric RNAs synthesized during viral replication and cut them into small oligonucleotides (siRNA). The siRNA molecules that serve as guides for an RNA-induced silencing complex (RISC) that recognizes homologous gene transcripts (Baulcombe, 1999; Chicas and Macino, 2001) targeting them for hydrolysis and thereby reduces expression of the target gene.

VIGS provides a rapid method for loss of gene function assay, avoiding the need for time-consuming transformation and regeneration processes. In addition, VIGS provides the opportunity to overcome functional redundancy by suppressing all or most members of a gene family (Burch-Smith et al., 2004). Vectors based on tobacco rattle virus (TRV) with a wide host range have been shown to function effectively in *Nicotiana benthamiana* (Liu et al., 2002a), tomato (Liu et al., 2002b), petunia (Chen et al., 2004),

poppy (Wege et al., 2007) and *Aquilegia* (Gould and Kramer, 2007) for phytoene desaturase (*PDS*) silencing. Infected plants show characteristic photo-bleaching symptoms resulting from the decreased production of photoprotective carotenoid proteins and the subsequent breakdown of chlorophyll pigments. This phenotypic marker can be a potential reporter for examining the effect of silencing other target genes. In these previous studies, researchers reported that a highly homologous gene fragment was required to obtain high efficiency silencing. However, the sequence of *PDS* is not known for many species. In this paper, we describe a universal primer for isolation of *PDS* fragment from different plant species and report its successful use in a range of taxa.

MATERIALS AND METHODS

Plant Material

Seedlings of a range of species including petunia (*Petunia × hybrida*) 'Primetime Blue'; tomato (*Lycopersicon esculentum*) 'New Yorker'; Yesterday, today and tomorrow (*Brunfelsia glandiflora*); daisy 'Alaska'; gerbera (*Gerbera × hybrida*); chrysanthemum (*Dendranthema grandiflorum*) 'Veracruz'; lettuce (*Lactuca sativa*) 'Red Sails'; impatiens (*Impatiens wallerana*) 'Orange Bling'; Phalaenopsis orchid (*Phalaenopsis amabilis*); rose (*Rosa × hybrida*) 'Magnum'; four o'clock (*Mirabilis jalapa*); and bean (*Phaseolus vulgaris*) 'Kentucky Blue' and 'Golden Wax' were grown under 16h light/8h dark cycles at approximately 20–25°C.

Plasmid Construct

PDS constructs: A 520 bp fragment of the *PDS* gene was amplified from leaf cDNA of each species using primers 5'-GGTGGAAAG (g/a) T (a/g/t) GCTGC (a/t/c) TGG-3' and 5'-GCCAT (t/c) TT (g/a/t) GAACCATG (t/c) TT (t/c) TCCTG-3'. The resulting product was cloned into pGEM-T easy (Promega) for amplification, sequencing and cloning. The *PDS* cDNA fragment was excised using *Eco*RI digestion from the plasmid, then subcloned into pTRV2 to generate a pTRV2 *PDS* construct specific to each species.

Agrobacterium-Mediated Infection

The constructs, pTRV1 (TRV RNA1 construct), and pTRV2 (RNA2 (empty vector control) or RNA2+*PDS* fragment) constructs were transformed into *Agrobacterium* strain GV3101 by electroporation. The bacteria were cultured overnight at 28°C in LB medium with 40 mg/L Kanamycin and 20 mg/L Gentamycin. The *Agrobacterium* cells were then harvested and resuspended in inoculation buffer (10 mM MgCl₂, 10 mM MES, 200 μM acetosyringone) to an O.D. of 1~2 and left at room temperature for at least 4h. The bacteria containing pTRV1 and the bacteria containing pTRV2 or pTRV2 *PDS* were mixed together in a 1:1 ratio. The leaves of seedlings were inoculated with the mixed bacteria culture using a 1 ml disposable syringe without a needle (for daisy and tomato) or by vacuum infiltration (for lettuce and impatiens). Infected plants were incubated in growth chambers under 16h light/8h dark cycles at the temperature of 20–22°C.

RT-PCR Analysis

Total RNA was extracted from lettuce leaves using TRIzol Reagent (Invitrogen) and treated with RNase-free DNase (Ambion) to remove any contaminating genomic DNA. The first strand cDNA was synthesized using 2 μg total RNA, oligo d(T) primer, random hexamer, and superscript reverse transcriptase (Invitrogen). This cDNA was normalized by real-time quantitative PCR using 18S rRNA primer (5'-CATGGCCGTTCTT AGTTGGTGGAG-3' and 5'-AAGAACGCTGGCCCGAAGGGAT AC-3').

The primers for amplifying *PDS* transcripts by semi-quantitative PCR were designed outside the region targeted for gene silencing to avoid amplification from the pTRV *PDS* construct. These primers were 5'-CTTGCAAGCCAATTGTTGA-3' and 5'-TTGTAGGGTCGACATGGTT-3'.

RESULTS AND DISCUSSION

Design of Primers to Amplify *PDS* Gene Fragments from Different Plant Species

A BLAST search for *PDS* sequences from a wide range of taxa permitted us to design a set of degenerate primers that would amplify a *PDS* fragment from known species, and therefore, most probably from species where the gene's sequence is unknown. An approximately 520 bp fragment of the *PDS* gene was amplified by the degenerate primers from all tested species (Fig. 1). A comparison of the *PDS* fragment sequences from 9 different plant species reveals a similarity of higher than 80% but in most cases less than the 90% homology required for efficient VIGS (Fig. 2). It seems likely that most other species will include the highly conserved region of the *PDS* gene amplified by this pair of degenerate primers.

Host Range of TRV-Induced *PDS* Gene Silencing

Fragments isolated from the target species using our universal primers were very effective when used in VIGS silencing of *PDS*. Developing leaves of pTRV2-*PDS* infected plants showed the strong photobleaching phenotype that indicated movement of the virus and its effectiveness in silencing the native *PDS* gene in bean, impatiens, daisy, and tomato (Fig. 3). No photo-bleached phenotype was found in the H₂O or pTRV2 empty vector controls (data not shown).

PDS gene transcripts were clearly evident in RNA extracted from non-silenced leaves and vector control, but barely detected in that from photo-bleaching leaves of lettuce by RT-PCR (Fig. 4). The result suggested that the photo-bleaching phenotype was caused by the down-regulation of the *PDS* gene.

In previous VIGS studies of a wide range of different ornamentals (Chen et al., 2003), only *N. benthamiana* and *P. hybrida* (both from the Solanaceae) showed the *PDS* phenotype. We now suspect that this negative result reflected a lack of homology between the *PDS* of *N. benthamiana* (the source of the *PDS* fragment used in the study) and the *PDS* sequences in the other target species.

Efficiency of VIGS in Different Species

Although we were able to silence *PDS* in all of the species that we tested, efficiency (% plants showing phenotype), and extent of silencing varied among taxa. Increasing the concentration of the *Agrobacterium* inoculum (to an OD₆₀₀ of 2.0) increased the frequency of silencing in impatiens plants (Fig. 5). In most tested species, however, the silencing symptom was local, confined to one or two leaves (Fig. 3). To obtain systemic symptoms in such species, it may be necessary to develop techniques to improve viral movement, and/or inhibit the plant's antiviral mechanism.

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Figures

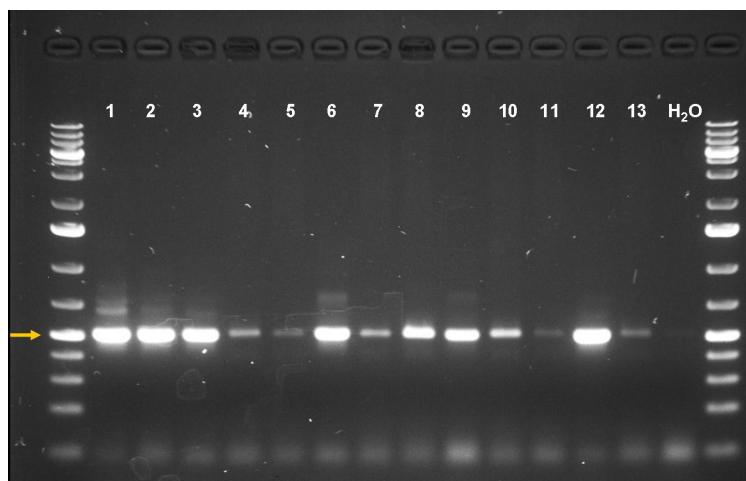


Fig. 1. *PDS* gene fragments were amplified by the universal primers from different species. 1: Petunia; 2: Tomato; 3: Brunfelsia; 4: Daisy; 5: Gerbera; 6: Chrysanthemum; 7: Lettuce; 8: Impatiens; 9: Orchid; 10: Rose; 11: Mirabilis; 12: Pole bean; 13: Bush bean. The size of the *PDS* fragment is approximately 520 bp (arrow).

Rose	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Mirabilis	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Impatiens	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Bean	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Mum	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Daisy	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Gerbera	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Tomato	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA
Brunfelsia	GGTGGAAAG-ATTGCTGCTTGGAAAAGATAAAGATGGAGACTGGTATGAGACAGGCCATA

Rose	TATACTTTGGGGCTATCCAAATATTCAAACTTGTGGAGAGCTTGGTATCAATGA
Mirabilis	CATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGTATTAATGA
Impatiens	CATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA
Bean	CATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA
Mum	CATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA
Daisy	CATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA
Gerbera	CATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA
Tomato	TATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA
Brunfelsia	TATATTCTTCGGGGCTTACCCAAATATTCAAACTTGTGGAGAGCTTGGCCTTAATGA

Rose	TGATTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Mirabilis	TGTTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Impatiens	CAGGTCACATGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Bean	TGTTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Mum	TAGACTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Daisy	TAGACTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Gerbera	AAGATTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Tomato	TGATTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT
Brunfelsia	TGATTGCACTGGAAAGAACACTTGTGATATTTCGATGCCAATGCAAGCAGGAGAGTT

Rose	CAGCGGTTTGATTCCCTGAAGTCTGCGCACCCCTAAATGGAATATGGGCATAT
Mirabilis	CAGCGGTTTGATTCCCTGAAGTCTGCGCACCCCTAAATGGAATATGGGCATAT
Impatiens	CAGCGGTTTGATTCCCTGAAGTCTGCGCACCCCTAAATGGAATATGGGCATAT
Bean	TAGTCGATTGATTCCTCCCGAAATCTTCCCGTCCCCATTAATGGAATATGGGCATAT
Mum	TAGTCGATTGATTCCTCCCGAAATCTTCCCGTCCCCATTAATGGAATATGGGCATAT
Daisy	TAGTCGATTGATTCCTCCCGAAATCTTCCCGTCCCCATTAATGGAATATGGGCATAT
Gerbera	CAGCGGTTTGATTCCCGAAAGCTTACCCGGCTCTTAAATGGAATATGGGCATAT
Tomato	CAGCGGTTTGATTCCCGAAAGCTTACCCGGCTCTTAAATGGAATATGGGCATAT
Brunfelsia	CAGCGGTTTGATTCCCGAAAGCTTACCCGGCTCTTAAATGGAATATGGGCATAT

Rose	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Mirabilis	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Impatiens	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Bean	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Mum	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Daisy	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Gerbera	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Tomato	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC
Brunfelsia	AAAGAACAACTGAGATGCTGACATGGGAGAAAAAGTGAAGTGTGATCAGGACTTGTGCC

Rose	AGAACATTCTGGGTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Mirabilis	TGCTATTGCTGGGTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Impatiens	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Bean	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Mum	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Daisy	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Gerbera	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Tomato	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG
Brunfelsia	AGCATATTGATTTGGCTGGACAGGCTTATGTTGAAGCTCAGGATGGCTTGTACTGTAAGGAGTG

Rose	GATGACAAAAACAGGGATACTGATGCGTAATCTGAGGTTTATGCGCATGTCAA
Mirabilis	GATGAGGAAGCAAGGTGACTCTGATCGAGTGAATGAGATTATTGCGCATGTCAA
Impatiens	GATGCAAAACAGGGATACTGAGGCTTACCCGGATCAGGCTTACACTGAGATTTTGCGCATGTCAA
Bean	GATGATAAAACAGGGTTACCTGACGAGTAACTGAGGCTTACACTGAGATTTTGCGCATGTCAA
Mum	GATGAGACAGGGAGGATAACCCGGATCAGGCTTACACTGAGGTTTATGCGCATGTCAA
Daisy	GATGAGAAAGCAAGGCTACAGGATCAGGCTTACACTGAGGTTTATGCGCATGTCAA
Gerbera	GATGAGAAAGCAAGGCTACAGGATCAGGCTTACACTGAGGTTTATGCGCATGTCAA
Tomato	GATGAGAAAGCAAGGCTACAGGATCAGGCTTACACTGAGGTTTATGCGCATGTCAA
Brunfelsia	GATGAGAAAGCAAGGCTACAGGATCAGGCTTACACTGAGGTTTATGCGCATGTCAA

Rose	GGCCATTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Mirabilis	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Impatiens	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Bean	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Mum	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Daisy	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Gerbera	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Tomato	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA
Brunfelsia	GGCATTTAACTTATTAACTCTGATGAGCTTAACTGCAATGCTTATGATGCTTGTAA

Rose	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Mirabilis	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Impatiens	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Bean	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Mum	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Daisy	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Gerbera	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Tomato	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA
Brunfelsia	TCGATTTCCTTCAGGGAAAAACATGGTTCAAAAAATGGCA

Fig. 2. Multiple sequence alignment of the *PDS* fragments isolated from the 9 target plant species.

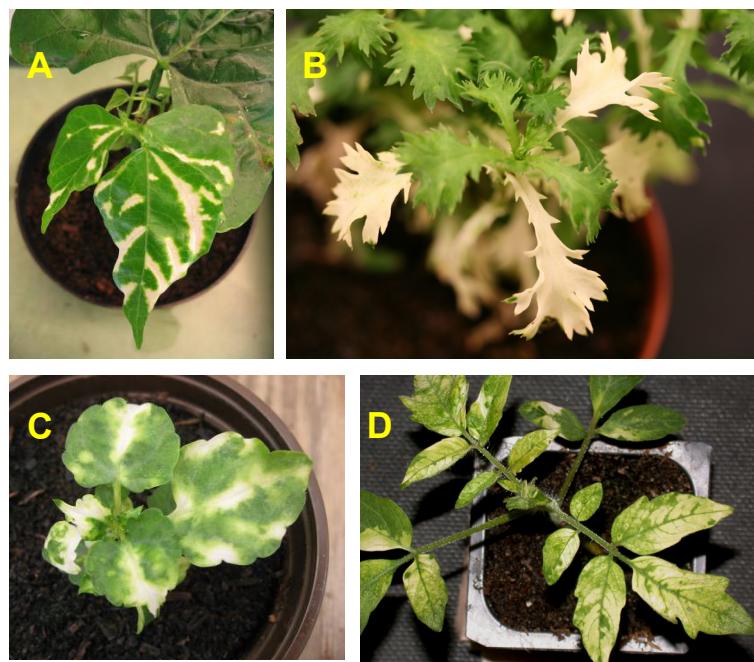


Fig. 3. Photobleaching phenotype resulting from VIGS silencing of *PDS* in different plant species using fragments isolated with the universal primers. A: Henderson's Baby Bush Lima Bean, B: Daisy 'Alaska', C: Impatiens 'Orange Bling', D: Tomato 'New Yorker'.

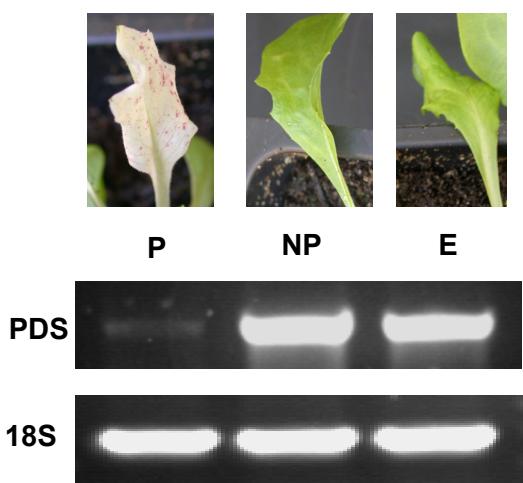


Fig. 4. Abundance of *PDS* transcripts in 'Red Sails' lettuce plants after VIGS silencing. P-silenced tissue, NP-non-silenced tissue, E-empty vector control.



Fig. 5. Effect of *Agrobacterium* concentration on silencing PDS in impatiens plants.

