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Promotor (FLT) for the Full-Length Transcript of Peanut Chlorotic Streak Caulimovirus (PCLSV) and Expression of Chimeric Genes in Plants

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US005850019A

United States Patent [19][11] **Patent Number:** **5,850,019****Maiti et al.**[45] **Date of Patent:** **Dec. 15, 1998**

[54] **PROMOTER (FLT) FOR THE FULL-LENGTH TRANSCRIPT OF PEANUT CHLOROTIC STREAK CAULIMOVIRUS (PCLSV) AND EXPRESSION OF CHIMERIC GENES IN PLANTS**

[75] Inventors: **Indu B. Maiti**, Lexington, Ky.; **Robert J. Shepperd**, Portland, Oreg.

[73] Assignee: **University of Kentucky Research Foundation**, Lexington, Ky.

[21] Appl. No.: **692,511**

[22] Filed: **Aug. 6, 1996**

[51] **Int. Cl.⁶** **A01H 5/00**; A01H 5/10; C07H 21/04; C12N 1/21; C12N 5/14; C12N 15/82

[52] **U.S. Cl.** **800/205**; 435/172.3; 435/243; 435/252.8; 435/320.1; 435/419; 536/24.1; 800/250; 800/DIG. 9; 800/DIG. 13; 800/DIG. 14; 800/DIG. 17; 800/DIG. 24; 800/DIG. 26; 800/DIG. 27; 800/DIG. 42; 800/DIG. 43; 800/DIG. 44; 800/DIG. 56; 800/DIG. 57; 800/DIG. 58; 800/DIG. 63; 800/DIG. 65

[58] **Field of Search** 536/24.1, 23.1, 536/23.2; 435/320.1, 410, 414, 419; 800/205, 250, DIG. 9, DIG. 13, DIG. 17, DIG. 24, DIG. 26, DIG. 27, DIG. 44, DIG. 42, DIG. 14, DIG. 43, DIG. 56, DIG. 57, DIG. 58, DIG. 65, DIG. 69, DIG. 63

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Attorney, Agent, or Firm—McDermott, Will & Emery

[57] **ABSTRACT**

The isolation, modification and use of wild-type and modified viral FLT promoters of peanut chlorotic streak caulimovirus (PCISV) in the expression of chimeric genes in plant cells. The FLT promoter from PCISV has been modified to have duplicated enhancer domains.

17 Claims, 9 Drawing Sheets

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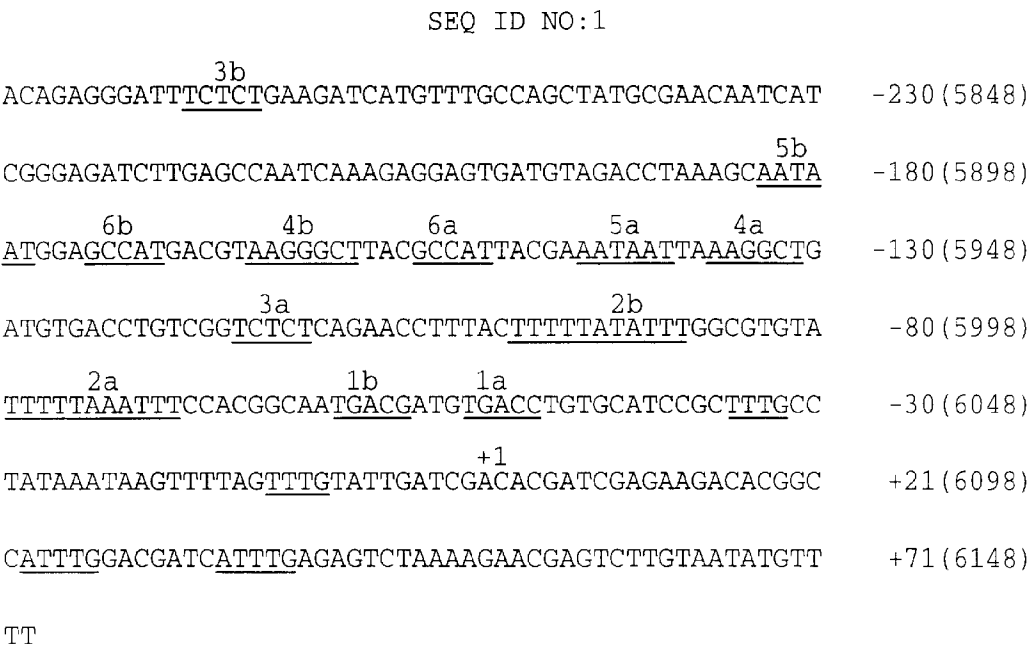


FIG. 1

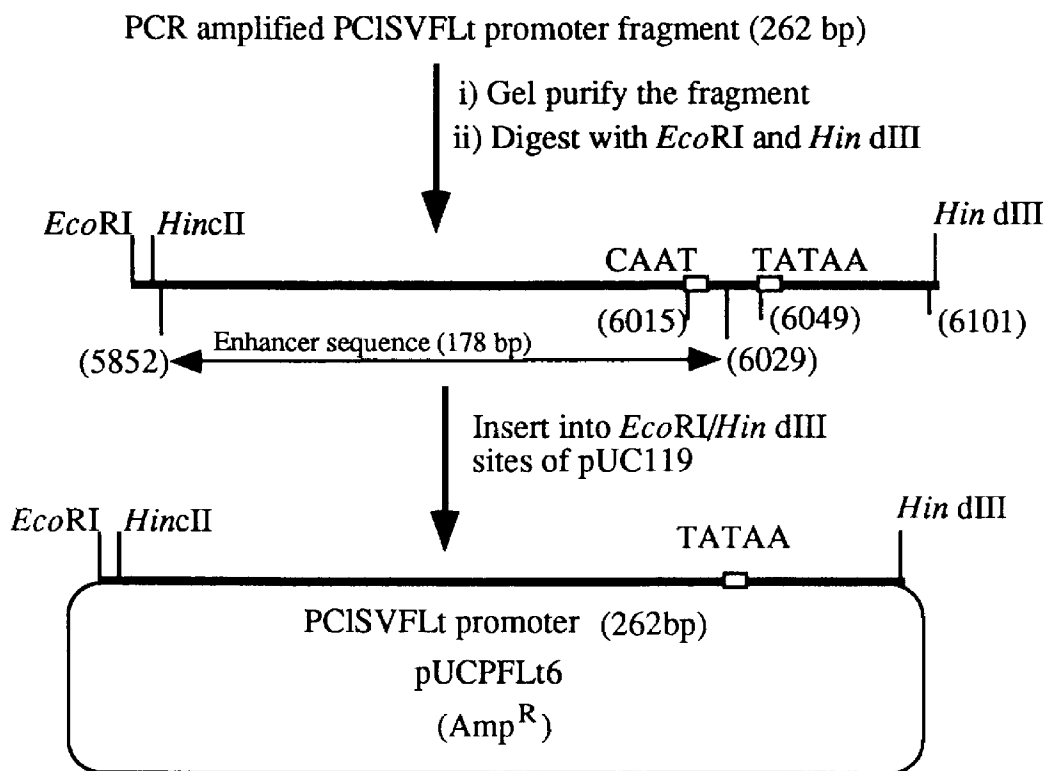


FIG. 2A

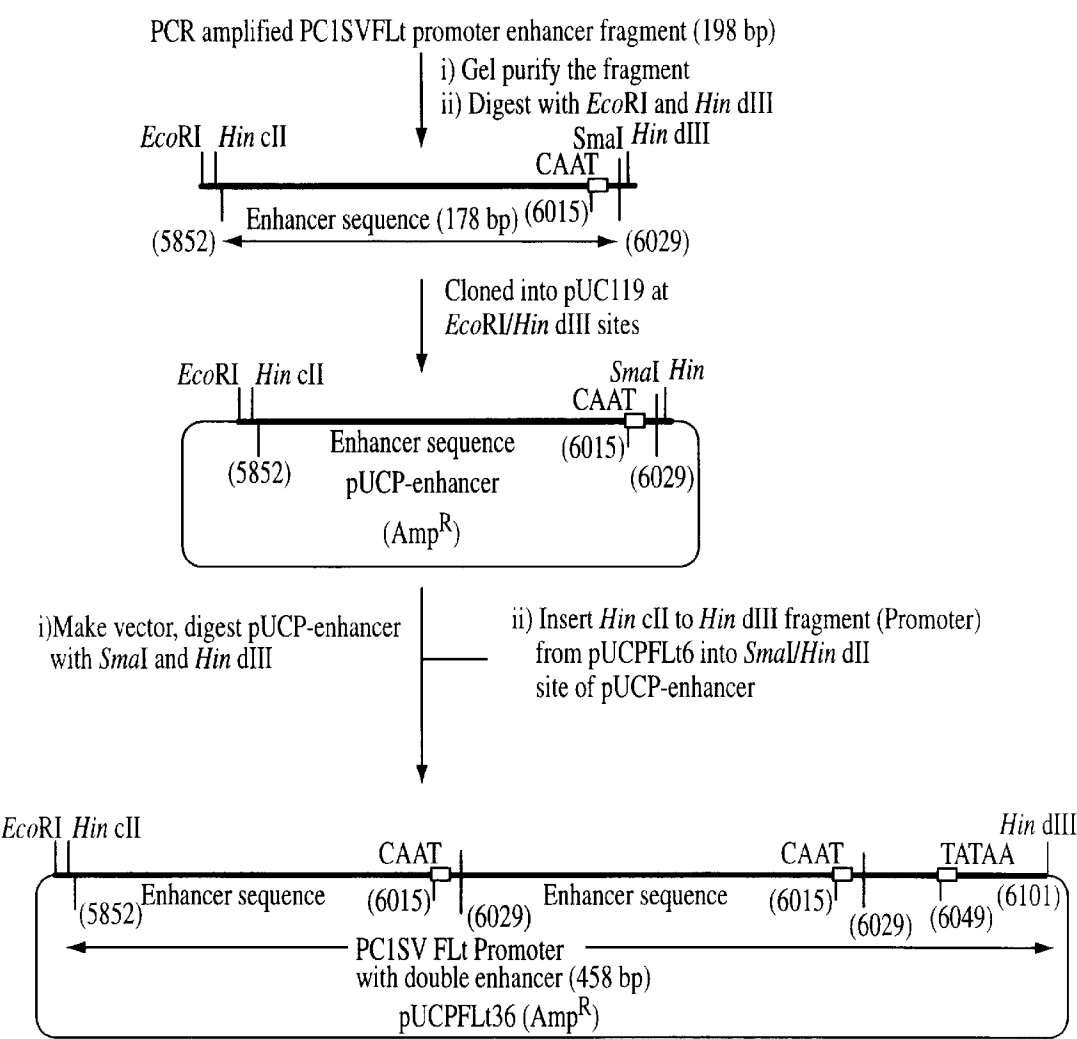


FIG. 2B

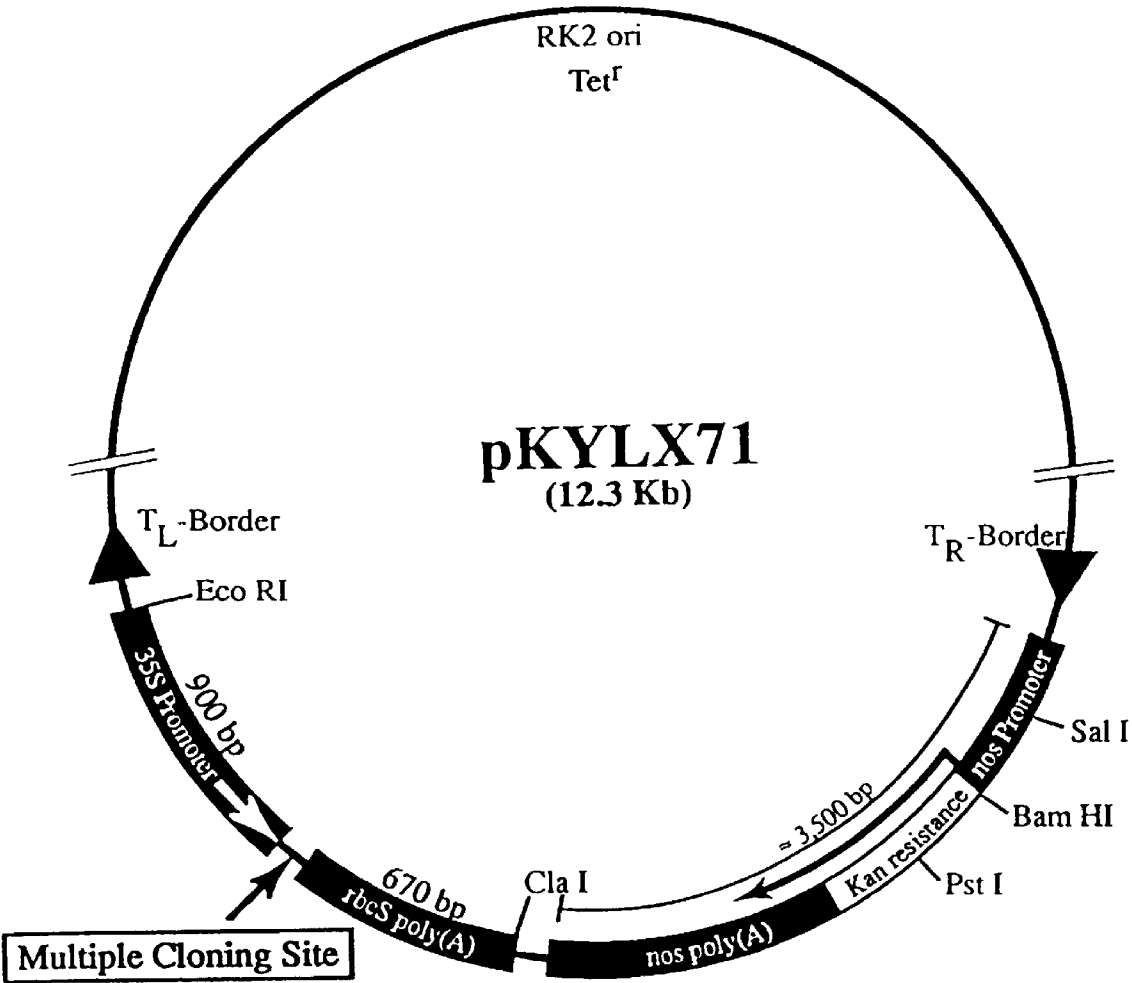


FIG. 3

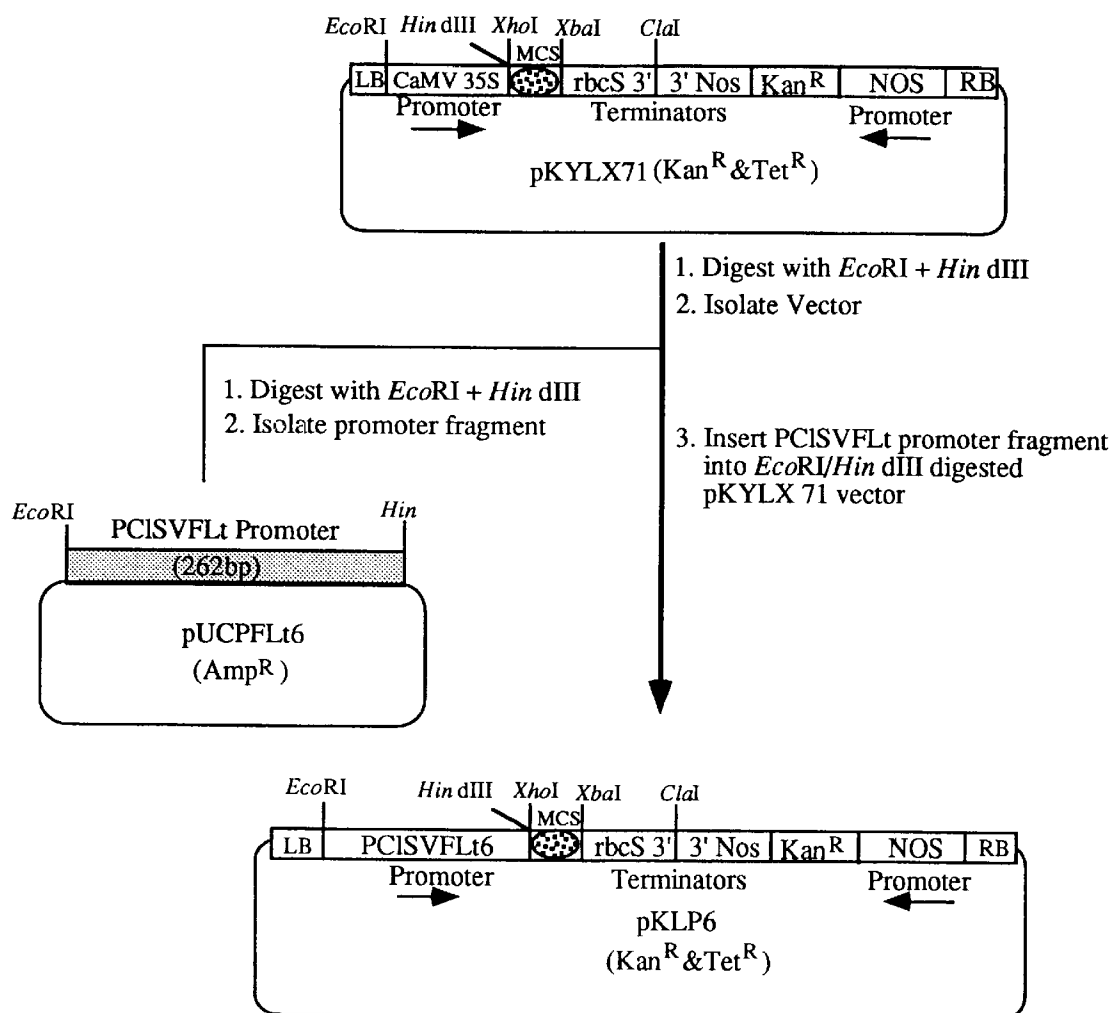


FIG. 4

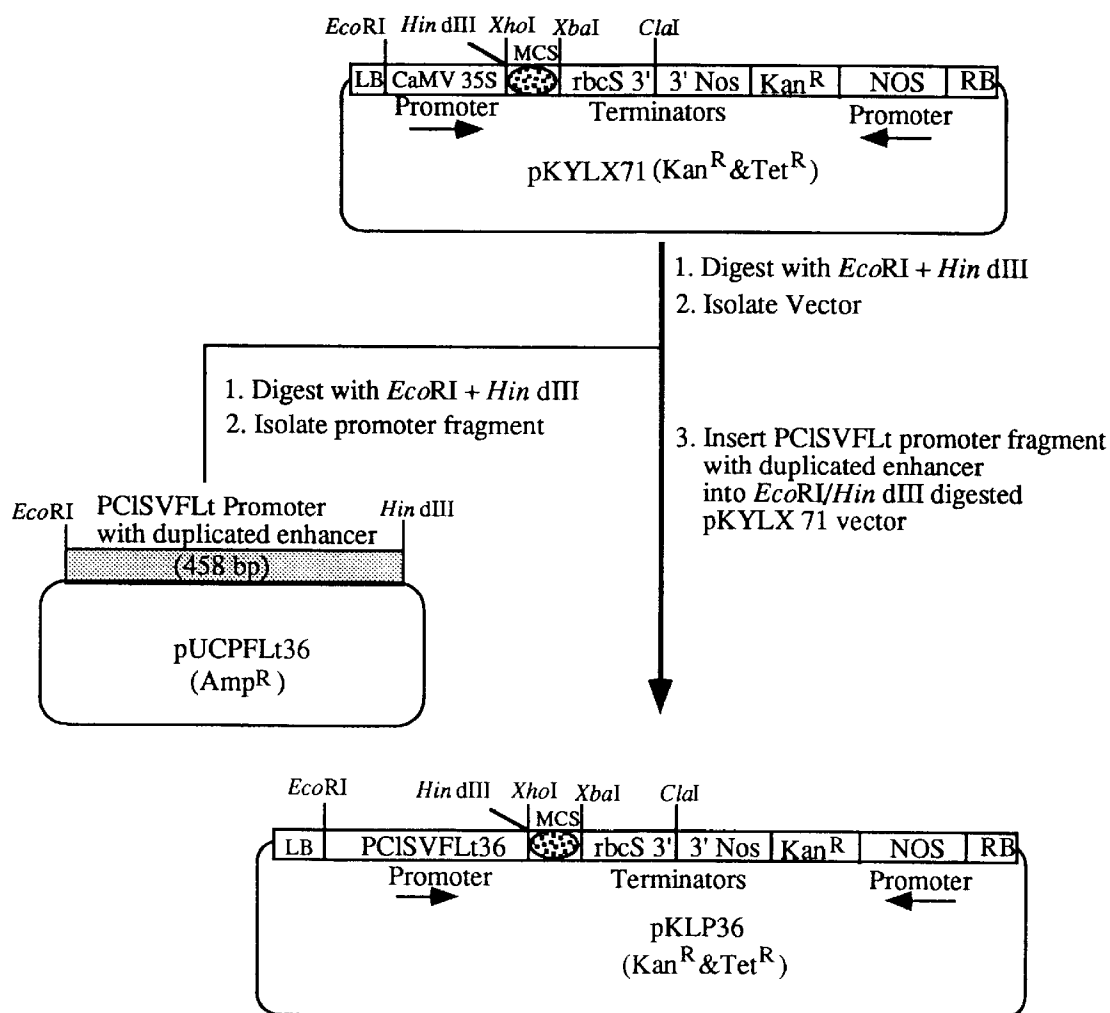
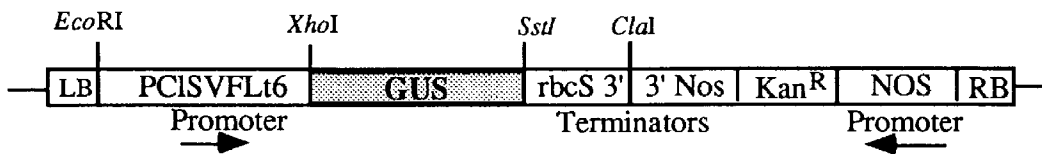


FIG. 5

(Construct # 114-GUS)

pKLP6GUS



(Construct # 116-GUS)

pKLP36GUS

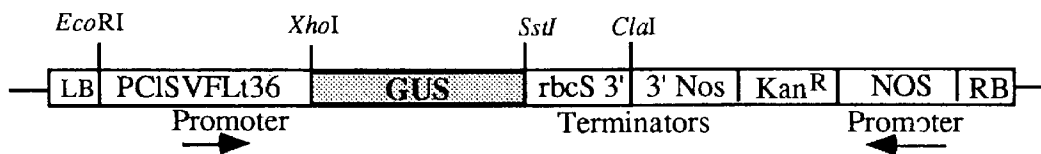


FIG. 6

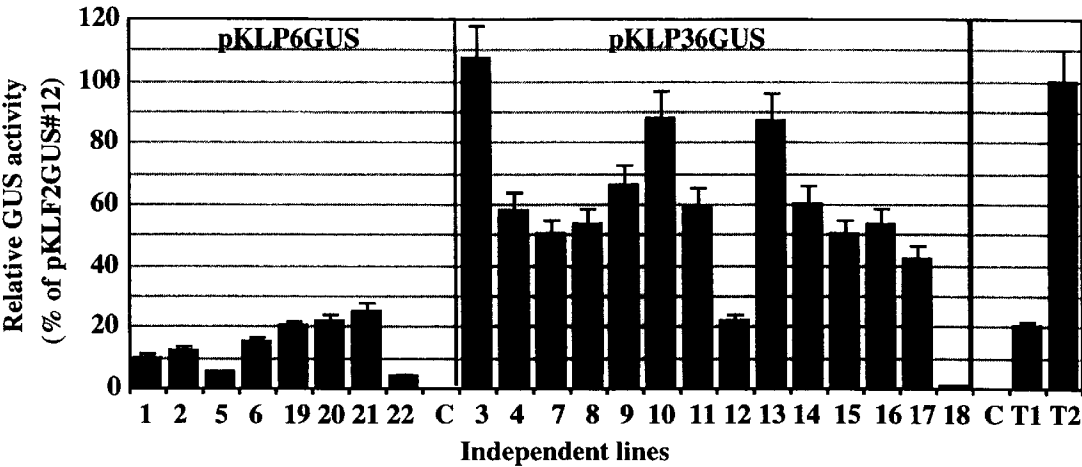


FIG. 7



FIG. 8A

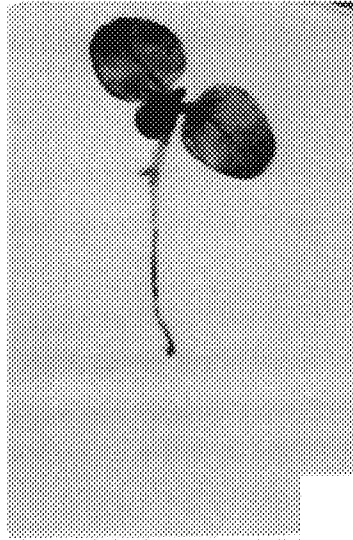


FIG. 8B

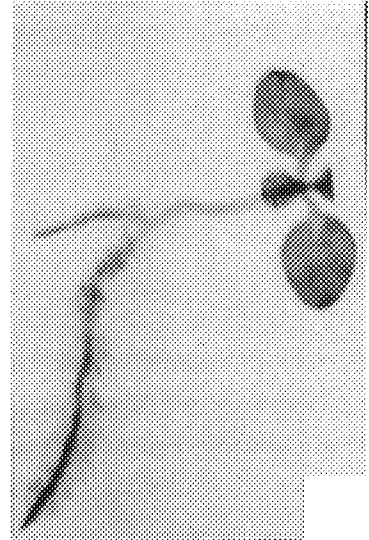


FIG. 8C



FIG. 8D

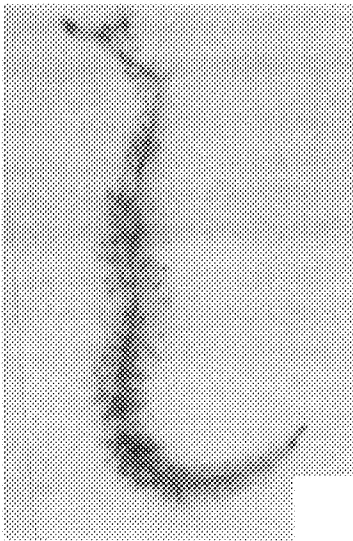


FIG. 8E

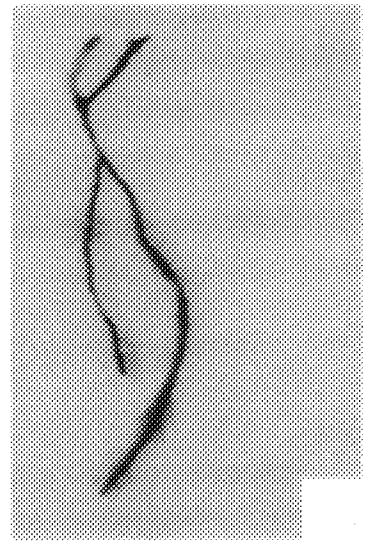


FIG. 8F

PROMOTER (FLT) FOR THE FULL-LENGTH TRANSCRIPT OF PEANUT CHLOROTIC STREAK CAULIMOVIRUS (PCISV) AND EXPRESSION OF CHIMERIC GENES IN PLANTS

TECHNICAL FIELD

The present invention relates to the fields of plant genetic engineering and plant molecular biology. More particularly, the present invention relates to the isolation, modification and use of wild-type and modified viral FLt promoters of peanut chlorotic streak caulimovirus (PCISV) in the expression of chimeric genes in plant cells. The FLt promoter from PCISV has been identified by the present inventors and modified to have duplicated enhancer domains.

The FLt promoter with its single or double enhancer domains when linked to heterologous coding sequences to form chimeric gene constructs showed high levels of expression of these genes in cells and transgenic plants. These chimeric genes have been shown to be well expressed in plant cells. The FLt promoter with its double enhancer domain gives better expression of genes compared to the FLt promoter with its single enhancer domain in transformed plants. However, both plasmids with enhancer domains show improved levels of expression over promoters without enhancer domains. This invention also includes plant cells, plant tissue, and differentiated plants and seeds under control of the FLt promoter of PCISV.

The invention is particularly directed to plasmids such as pPCSV22CAT containing the full-length transcript promoter of the peanut chlorotic streak caulimovirus. The plasmid is used to express chimeric genes in plants.

BACKGROUND ART

A virus is a group of submicroscopic infective agents with double or single stranded DNA or RNA as core genetic material surrounded by a protein (and lipid in some cases) shell called a 'capsid' or 'coat'. It has no semipermeable membrane and it can multiply only in living cells using host cellular components. The short segment of the virus genetic material (FLt promoter) used in this invention can not infect plants or other organisms to cause disease. It is useful with selected foreign genes to obtain expression of these genes in other plants to confer useful properties to those transgenic plants.

The caulimoviruses and their promoters

The following is a description of caulimoviruses also called plant pararetroviruses. Caulimoviruses derived their name from cauliflower mosaic virus (CaMV), the type member of the group (for reviews see Shepherd, 1989; Covey and Hull, 1992). More than a dozen types of caulimoviruses have been described to date. All have small circular DNA molecules as their genetic material. The genomes of CaMV (Gardner, et al., 1981) and four other members of this group, namely carnation etched ring virus (CERV), (Hull, et al., 1986), figwort mosaic virus (FMV), (Richins, et al., 1987) soybean chlorotic mottle virus (SOCMV), (Hasegawa, 1989), and peanut chlorotic streak virus (PCISV) (Richins, 1993) have been fully sequenced. CaMV is a circular double stranded DNA virus with a genome size of approximately 8 kb. It is organized into seven open reading frames (genes) and two intergenic regions. In the case of CaMV and by analogy PCISV, the polypeptides corresponding to the six genes (I to VI) have been detected in infected cells and their functions have been identified. The cell-to-cell movement function (Thomas, et

al., 1993; Ducasse et al., 1995), aphid-transmission factor (Daubert et al., 1983; Woolson, et al., 1983), minor capsid protein (Giband, et al., 1986), major capsid protein (Daubert, et al., 1982), reverse transcriptase (Takatsui, et al., 1992), and post-transcriptional transactivator (Bonneville et al., 1989) (also the inclusion body protein, Odell and Howell, 1980) are associated with ORFs I to VI respectively.

Gene VII protein was not detected in vivo (Wurch, et al., 1991); and its function is not clearly established. However a sequence located with this ORF of FMV is involved in translation of viral genes (Gowda, et al., 1991). The viral genome is replicated through reverse transcription of the terminally redundant full-length transcript (Bonneville and Hohn, 1993) by a virus encoded reverse transcriptase. Two major viral transcripts, known as 35S RNA and 19S RNA are synthesized exclusively from the minus strand DNA by the host RNA polymerase II (Odell, et al., 1981; Howell and Hull, 1978).

The large intergenic region (L-IR) which resides between gene VI and VII, contains the promoter (35S) for the full-length transcript which spans the entire viral genome (Dixon and Hohn, 1984; Scholthof, et al., 1992). The 35S RNA serves as template for minus strand DNA synthesis by viral gene V encoded reverse transcriptase (Gordon, et al., 1988). The small intergenic region (S-IR) residing between gene V and gene VI contains a promoter (19S) which transcribes gene VI only (Odell and Howell, 1980). The PCISV is apparently lacking the S-IR sequence, however both FMV (Scholthof, et al., 1992) and PCISV (Richins, 1993) have also been shown to have transcripts similar to the 19S and 35S RNA found in CaMV infected plant cells.

Regulatory elements of the cauliflower mosaic virus 35S promoter

The CaMV 35S promoter, which spans about 941 base pair (bp) upstream from the transcription start site, has been shown to be active in various monocot and dicot cells. The cis-regulatory elements that are involved in directing transcription initiation reside within this region. The CaMV 35S promoter has a modular construction with elements consisting of an enhancer (Lam, 1994, and references there in) similar to those of other promoters like that of SV40 in mammalian systems (Ondek, et al., 1987; Schirm, et al., 1987; Fromental, et al., 1988). The 5' deletion analysis of CaMV35S promoter, studied in transformed tobacco calli or a protoplasts transient assay system, indicates that a promoter fragment of 343 bp upstream from the transcription start site is sufficient for high promoter activity (Odell, et al., 1985; Ow, et al., 1987).

The high promoter activity is the result of synergistic and combinatorial effects of enhancer elements residing in the -343 to -46 region upstream of the TATA element promoter (-46 to +8) (Fang, et al., 1989, Benfey, et al., 1989, Benfey and Chua, 1990, Benfey, et al., 1990a and Benfey et al., 1990b).

Sequence motifs and Trans-acting factors in the CaMV promoter

Several protein binding sequence motifs have been identified in the enhancer region of the 35S promoter (Lam, et al., 1989; Lam and Chua, 1989; Prat, et al., 1989; Bouchez, et al., 1989, Yanagisawa and Izui, 1992). Identical or similar sequence motifs are also present in promoters of other caulimoviruses (Bouchez, et al., 1989; Sanger, et al., 1990; Cooke and Penon, 1990; Richins, et al., 1993). Two nuclear binding protein factors, known as Activating Sequence Factor-1 and -2 (ASF-1 and ASF-2) from tobacco have been well characterized. ASF-1 binds to the activating sequence as-1 (-82 to -62) region of 35S promoter. Two TGACG

motifs within this site are essential for DNA-protein interaction (Lam, et al., 1989). The as-1 motif is also found in full-length transcript promoters from other caulimovirus including FMV (Sanger, et al., 1990, and present studies), PCISV (Richins, 1993) and MMV (Shepherd group, unpublished observation).

Modification of Promoter with multiple copies of an enhancer domain

Single or multiple copies of enhancer sequences from the CaMV 35S promoter can increase homo- and heterologous promoter activity in an orientation-independent manner (Kay, et al., 1987; Ow, et al., 1987; Odell, et al., 1988; Fang, et al., 1989; Driesen, et al., 1993; Omirulleh, et al., 1993). The enhancement of promoter activity was proportional to the copy number of the enhancer sequence (Kay, et al., 1987; Ow, et al., 1987; Omirulleh, et al., 1993). Similar observation was made when single or multiple copies of the enhancer sequence was inserted upstream of the TATA element of the CaMV19S promoter (Ow, et al., 1987; Driesen, et al., 1993), rbcS-3A promoter (Fang, et al., 1989), the nos promoter (Odel, et al., 1988) or the FMV FLt promoter (Maiti, et al., 1995, 1996).

The engineering of novel traits in plants and other crops promises to be an area of great agricultural importance (Maiti and Hunt, 1992; Wagner, 1992). Plant genetic engineering techniques allow researchers to introduce heterologous genes of interest into plant cells to obtain the desired qualities in the plants of choice. Plant genetic engineering is leading to rapid progress in the production of economically valuable germplasm with improved characters or traits such as insect resistance, virus resistance, fungal resistance, herbicide resistance, bacterial or nematode pathogen resistance, cold or drought tolerance, improved nutritional value, seed oil modification, delayed ripening of fruits, and male sterility, to name a few. These germplasms provide enhanced developments in breeding programs for crops improvement as well as a better understanding of gene regulation and organization in transgenic plants. The expression of useful new traits in plants is a major focus in plant biotechnology.

Plant metabolic engineering is the application of genetic engineering methods to modify the nature of chemical metabolites in plants. For metabolic engineering where multiple genes need to be inserted into one cell, the use of different strong constitutive promoters is desirable in order to avoid genetic instability caused by recombination between identical or closely related promoter sequences, for example those taken from plants themselves. Through use of these promoter sequences the introduced genes can be transcribed to messenger RNA and then translated to resultant proteins to exhibit new traits or characters.

Besides developing useful traits in crops, transgenic plants lead to a further understanding of molecular pathways involved in disease development and secondary metabolism in plants. Moreover, by engineering plants with specific foreign genes, the responses of plants to abiotic and biotic stress and stress-related metabolism are analyzed. The invention described herein which develops gene vectors with newly defined promoters of the caulimoviruses advances this effort.

A wide variety of well-characterized genes of animal, human, bacterial and of plant origin, including those of several viruses, are available for engineering plants. For the most effective expression of this wide selection of genes either constitutive or regulated, versatile gene expression vectors are required. At the University of Kentucky, Dr. Arthur Hunt and his colleagues have developed a series of plant expression vectors (Schardl, et al., 1987) with a

constitutive 35S promoter from cauliflower mosaic virus (CaMV) which have been successfully used to produce transgenic plants (Maiti, et al., 1988, 1989, 1991, 1993, 1994, 1995; Graybosh, et al., 1989; Berger, et al., 1989; Yeargan, et al., 1992; Liod, et al., 1992).

The most widely used promoter for plant transformation, as described earlier, has been the 35S promoter of CaMV. It is active in a wide variety of plants and tissues. It also is the most thoroughly characterized promoter with respect to the sequence elements active in its transcriptional activity (Benfey and Chua, 1990. Kay, et al., 1987 showed that the transcriptional activity of the CaMV 35S promoter could be increased approximately tenfold by making a tandem duplication of 250 base pairs of upstream sequence. Similar observations have been made with other promoters (McNeill, et al., 1989). A similar construct has been tested with the FMV—and FLt promoters.

Certain promoters have a specific modular sequence which makes them either tissue-specific, developmentally regulated or environmentally regulated for the selective expression of genes in cells. Promoters capable of directing RNA synthesis at higher rates compared to other promoters are desirable for many purposes. If these promoters are able to direct the expression of genes in most types of plant tissues, they are defined as constitutive promoters. Previous work had established that the CaMV 35S promoter is one of the strongest constitutive promoters. The transcriptional activity of the CaMV 35S promoter is the result of synergistic and combinatorial effects of enhancer elements residing upstream of the TATA element. Single or multiple copies of the enhancer sequences from the CaMV 35S promoter can also increase the activity of heterologous promoters in an orientation-independent manner. The enhancement of promoter activity has been found to be related to the copy number of the enhancer sequence. We have developed expression vectors with the PCISV promoter with its single and duplicated enhancer domains. The upstream enhancer elements of the strong constitutive promoter from the full-length transcript of FMV or PCISV has been doubled in a strategy to strengthen this promoter even further.

Promoters from other caulimoviruses such as FMV, and MMV, as well as the better characterized CaMV 35S promoter are found to be useful for plant genetic engineering. The Monsanto Co. has recently patented the 35S and the 19S promoters of CaMV in USA, and the full-length transcript promoter from FMV in Europe. The inventors have now developed new promoters of equal or better strength.

U.S. Pat. No. 5,306,862 to Chappell, et al., discloses a method and composition for increasing sterol accumulation in higher plants. Column 8, lines 44–46 discloses the cauliflower mosaic virus promoter 35S.

U.S. Pat. No. 5,349,126 to Chappell et al., discloses a process and composition for increasing squalene and sterol accumulation in higher plants. Column 4, lines 20–24 describe the cauliflower mosaic virus 35S promoter. The patent describes the pKYLX71 recombinant plasmid.

Chemical Abstracts, Volume 118, Abstract No. 120793n, 1993, discloses the gene I of peanut chlorotic streak virus.

Chemical Abstracts, Volume 118, Abstract No. 251150y, 1993, discloses a physical map of the peanut chlorotic streak virus which is transmissible in plants of Leguminosae and Solanaceae. The virus was determined not to be related to the cauliflower mosaic virus and the figwort mosaic virus. Polypeptides were purified of the peanut chlorotic streak virus having 58 and 51 kDa. The virus is found to have a 8.1 kilo base pair length.

Chemical Abstracts, Volume 122, Abstract No. 232376t, 1995, discloses a molecular analysis of the essential and nonessential genetic elements of the peanut chlorotic streak caulimovirus.

Chemical Abstracts, Volume 122, Abstract No. 235454c, 1995, discloses reduced accumulation of tobacco mosaic virus in upper of leaves and plants inoculated with the peanut chlorotic streak caulimovirus.

Chemical Abstracts, Volume 123, Abstract No. 307774c, 1995, discloses gene I mutants of peanut chlorotic streak virus. Gene I is suspected of encoding a protein for virus movement.

Chemical Abstracts, Volume 106, Abstract No. 171526yn, 1987, discloses properties of ribonucleic acid in coat protein of the peanut chlorotic ring model virus.

Chemical Abstracts, Vol. 116, Abstract No. 1417s, 1992 discloses the regions of sequence variation in caulimovirus gene VI. The figwort mosaic virus is used as a comparison.

Chemical Abstracts, Vol. 116, Abstract No. 3719r, 1992 discusses the disease syndrome associated with expression of gene VI and caulimoviruses. There is a correlation between the level of gene VI and coded protein found in the disease.

Chemical Abstracts, Vol. 116, Abstract No. 249819p, 1992 discloses the full-length transcript of the caulimovirus as a polycistronic messenger RNA whose genes are trans-activated by the product of gene VI. The results show that the genome of figwort mosaic virus contains two promoters.

Chemical Abstracts, Vol. 117, Abstract No. 186002q, 1992 discloses regulation of caulimovirus gene expression and involvement of cis-acting elements on viral transcripts.

Chemical Abstracts, Vol. 118, Abstract No. 230014s, 1993 discloses that a zinc finger of a caulimovirus is essential for infectivity but does not influence gene expression.

Chemical Abstracts, Vol. 122, Abstract No. 75400b, 1995, discloses that eukaryotic RNase H shares a conserved domain with caulimovirus protein.

Chemical Abstracts, Vol. 122, Abstract No. 232376t, 1995 discloses a molecular analysis of essential and non-essential genetic elements in the peanut chlorotic streak caulimovirus.

Chemical Abstracts, Vol. 123, Abstract No. 251578x, 1995 discloses regulatory elements involved in caulimoviral gene expression.

Plant expression vectors with the constitutive FLt promoter from PCISV have been developed by the present inventors.

The present inventors have overcome deficiencies in prior art concerning transgenic plant promoters, and have developed useful promoters from PCISV for high level expression of foreign genes, for example, in transgenic tobacco. These vectors are be useful for both direct DNA uptake by isolated protoplasts and Ti plasmid-mediated gene transfer. Enhanced levels of transcription via highly active promoters are essential for high levels of gene expression in transgenic plants.

SUMMARY OF THE INVENTION

These inventions are in general applicable to plant genetic engineering. Specifically, the present inventions relate to the promoters from peanut chlorotic streak virus (PCISV) and these promoters direct the expression of genes in plant cells. A conventional gene is composed of a promoter region, a sequence encoding a 5' non-translated leader sequence of the transcribed messenger RNA, the structural gene itself and a 3' polyadenylation sequence. The promoter is a DNA fragment composed of modular sequence which directs and regulates the transcription to messenger RNA, the first step in expression of a gene.

The proper regulatory signals/enhancer elements should be present in a defined location in order to express the inserted gene first as RNA and then as a resultant protein via

the process of translation. The 3'-polyadenylation sequence is a non-translated region which signals the adenylation of the 3' end of the RNA in order to stabilize the RNA in the cytoplasm for subsequent translation into protein.

An objective of the present invention is to define and document the strong constitutive FLt promoter of PCISV to be used for expression of chimeric genes in transgenic plants. An additional object is to describe a strategy to further strengthen the promoter from the full-length transcript of other members of the caulimoviruses including PCISV.

Thus the present invention provides a plasmid comprising a chimeric gene comprising a full-length transcript (FLt) promoter from peanut chlorotic streak virus (PCISV) operably linked to at least one heterologous gene sequence which is heterologous to the promoter.

The invention also provides for plant cells and transgenic plants which contain the plasmid of the invention.

The above and other objects of the invention will become readily apparent to those of skill in the relevant art from the following detailed description and figures, wherein only the preferred embodiments of the invention are shown and described, simply by way of illustration of the best mode of carrying out the invention. As is readily recognized the invention is capable of modifications within the skill of the relevant art without departing from the spirit and scope of the invention.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows the DNA sequence of the full-length transcript promoter from peanut chlorotic caulimovirus (PCISV; Richins, et al., 1993). The nucleotide sequence (PCISV coordinates 5799 to 6150, a 352 bp fragment) includes the 3' end of gene VI (SEQ ID NO:1), and part of the large intergenic region, presented from left to right in the 5' to 3' direction of the transcript.

FIGS. 2A and 2B show the construction strategy of PCISV FLt promoter with single and double enhancer domains.

FIG. 3 shows a physical map of pKYLX71.

FIG. 4 shows a physical map of pKLP6.

FIG. 5 shows a physical map of pKLP36.

FIG. 6 shows a schematic representation of chimeric GUS constructs used for assaying PCISVFLt promoter expression activity in transgenic plants.

FIG. 7 shows a PCISV FLt promoter activity in transgenic plants expressing a GUS reporter gene.

FIG. 8 shows histochemical localization of GUS activity in developing transgenic tobacco plants.

STATEMENT OF DEPOSIT

Plasmids pKLP6 and pKLP36 in *E. coli* TB1 have been deposited with the Agricultural Research Service (ARS) Patent Culture Collection (NRRL), 1815 North University Street, Peoria, Ill., USA, 61604, under the terms of the Budapest Treaty on Jul. 25, 1996. The deposit will be maintained for the life of the patent as required by Treaty.

DETAILED DESCRIPTION OF THE INVENTION

The invention provides for a plasmid or transformation vector comprising a chimeric gene comprising a full-length transcript (FLt) promoter from peanut chlorotic streak virus (PCISV) operably linked to at least one heterologous gene

sequence which is heterologous to the promoter. In a preferred embodiment the plasmid further comprises at least one PCISV enhancer domain. The plasmid may include a single or double enhancer domain.

In an alternative embodiment of the plasmid, the promoter directs transcription of heterologous genes downstream from said promoter, in plants. The promoter preferably comprises nucleotides 5799 to 6150 of the 3' portion of gene VI (SEQ ID NO:1) and a downstream intergenic region of the PCISV genome. The promoter may also comprise a 5' non-translated leader sequence from peanut chlorotic streak virus.

In a more preferred embodiment of the invention the plasmid further comprises a region of homology to an *Agrobacterium tumefaciens* vector and a T-DNA border region from *Agrobacterium tumefaciens*, wherein said chimeric gene is located between the T-DNA border and the region of homology. Similarly this embodiment of the invention may possess at least one PCISV enhancer domain. The expression vector may further comprise a disarmed plant tumor-inducing plasmid of *Agrobacterium tumefaciens*.

Preferred plasmids in accordance with the invention are plasmids selected from PKLP6, PKLP36 and PCSV22CAT. Methods for obtaining these plasmids and characteristics of these plasmids are described herein. For example, a plasmid of the invention may comprise, in the 5' to 3' direction, a) the PCISV FLt promoter with single enhancer; b) a 3' nontranslated polyadenylation sequence of rbcS E9 gene; and (c) a structural sequence encoding neomycin phosphotransferase II.

The invention provides for a plant cell which comprises the plasmid of the invention. The plant cell may express the plasmid with at least one PCISV enhancer domain.

More importantly, the invention provides for transgenic plants which express the plasmid of the invention. In a preferred embodiment the transgenic plant is selected from, but not limited to cotton, soy bean, alfalfa, oilseed rape, flax, tomato, sugar beet, sunflower, potato, tobacco, maize, wheat, rice, lettuce and banana plants. The transgenic plant may express a heterologous gene present in the plasmid of the invention in plant tissue selected from, but not limited to calyx, filament, pedicel, style, ovary, corolla, anther, stigma, embryo, seeds, leaf, stem and root tissues.

In sum, the invention includes any DNA construct comprising a PCISV promoter, and preferably includes a PCISV FLt promoter isolated from a PCISV protein-encoding DNA sequence. The DNA construct may be expressed in plant cells. The DNA construct is transcribed and translated in plant cells, and includes promoters such as a PCISV FLt promoter region free of PCISV protein-encoding DNA sequence and a PCISV FLt promoter region with a DNA sequence which is heterologous with respect to the promoter. In a preferred embodiment the construct comprises a DNA sequence which is heterologous with respect to the promoter and a 3' non-translated polyadenylation signal sequence.

Thus, the present invention includes the following: i) isolation of the promoter for the full-length transcript (FLt) of peanut chlorotic streak virus from a full-length viral DNA clone (Reddy, et al., 1993) as described below in Experimental Section. ii) The invention provides for modification of the PCISV promoter to include duplication or multimerization of the enhancer domain of the FLt promoter from PCISV. The FLt promoter sequence for PCISV is shown in FIG. 1. iii) The invention provides for use of PCISV

promoter in a method for transforming plant cells, expression vectors including PCISV promoter, a chimeric gene including PCISV promoter sequence, and transgenic plants, plant cells and seeds incorporating the PCISV promoter in a chimeric gene.

Experimental Procedures

Peanut chlorotic streak virus (PCISV) is a newly described member of the caulimovirus group (Reddy, et al., 1993). It has been partially characterized in this laboratory (Richins et al., 1993; Reddy, et al., 1993) These investigations provide the materials (DNA clones) for the invention described herein.

EXAMPLE 1

Construction of PCISV FLt promoter with its single and double enhancer elements and creation of plasmids pKLP6 and pKLP36

The construction strategy for isolating the PCISV FLt promoter and its enhancer is shown in FIGS. 2 A and B. The basic FLt promoter of PCISV, 150 bp (position 5852 to 6001 of the PCISV sequence) (SEQ ID NO:2) was isolated after amplification by PCR using oligonucleotides containing the appropriate sites to generate EcoRI-HincII sites at the 5' end and a HindIII site at the 3' end of the fragment. The promoter sequence was inserted as an EcoRI-HindIII fragment into the corresponding sites of the plant expression vector pKYLX71 (FIG. 3) and the plasmid pUC119. The resulting plasmids were designated pKLP6 (FIG. 4) and pUCPFLt6, respectively (FIG. 2A). The upstream sequence containing enhancer elements, a 78 bp (position 5852 to 5929) (SEQ ID NO:3) of the PCISV FLt promoter was amplified by PCR with oligonucleotides engineered for the EcoRI-HincII sites at the 5' end and the SmaI-HindIII sites at the 3' end of the fragment.

The enhancer element fragment was cloned into EcoRI and HindIII sites of pUC119 and the plasmid designated as pUCP-enhancer (FIG. 2B). The PCISV FLt basic promoter fragment as a HincII-HindIII fragment (isolated from pUCPFLt6) was inserted into the pUCP-enhancer plasmid after digestion with SmaI and HindIII. The resulting plasmid designated as pUCPFLt36 contains two copies of the enhancer elements (FIG. 2B). The PCISVFLt promoter with its double enhancer domain was inserted into the plant expression vector pKYLX71 at its unique EcoRI and HindIII sites that flank the promoter. The resulting plasmid was designated as pKLP36 (FIG. 5). The PCISV basic FLt promoter and enhancer elements was amplified from a full-length clone of PCISV (Reddy et al., 1993).

EXAMPLE 2

Testing the Expression Vectors with a GUS reporter gene Stable transformation and analysis of transgenic plants.

The reporter gene GUS was tailored by PCR to include just the coding sequence with the initiation and termination codons, flanked by a Xho I site at the 5' end and a Sst I site at the 3' end. The PCR isolated fragment for the reporter gene (GUS) was digested with Xho I and Sst I, gel purified and cloned into the corresponding sites of the plant expression vectors PKLP6 and pKLP36 and the resulting constructs pKLP6GUS and pKLP36GUS were introduced into *Agrobacterium tumefaciens* strain C58C1:pGV3850 by triparental mating. Tobacco (cv. Samsun NN) was transformed with the engineered *Agrobacterium* as described earlier (Maiti et al., 1993). To examine the integration of genes in transgenic plants, genomic DNA was isolated following the procedure (Thomson and Henry, 1993) for PCR analysis.

The integration of reporter GUS gene in the genome of transgenic plants (R0 and R1 progeny) was detected by PCR

amplification using appropriately designed oligonucleotides specific for the GUS gene sequence. Specificity of each PCR product was tested by Southern hybridization with a GUS probe. Although the GUS gene was used in this example as the gene heterologous to the PCISV promoter, any gene heterologous to the PCISV promoter which is desired to be expressed in a transgenic plant may be included in the plasmid. One of skill in the art can readily substitute any heterologous gene into the plasmid of the invention using conventional genetic engineering techniques.

Examples Heterologous Genes which may be used with PCISV FLt Promoter

Plant genetic engineering techniques allow researchers to introduce heterologous genes of interest into plant cells to obtain the desired qualities. A strong constitutive promoter like PCISV promoter is useful to direct the any gene to be used for plant genetic engineering, a field of biotechnology which is leading a rapid progress in the production of economically valuable germplasm with improved characters or traits such as:

1. Insect resistance, (developed with Bt toxin gene, α -amylase inhibitor gene).
2. Virus resistance, (developed with CP, protease or replicase gene).
3. Fungal resistance, (developed with chitinase gene, ribosome inhibiting protein gene, glucanase gene).
4. Herbicide resistance, (developed with acetolactate synthase, phosphinothricin acetyl transferase or bar gene, nitrilase gene, or 2,4-dichlorophenoxyacetate monooxygenase gene).
5. Bacterial or nematode pathogen resistance, (developed with α -hordothionin gene, Bt toxin gene, beet cyst nematode resistant locus).
6. Cold or drought tolerance.
7. Improved nutritional value, (developed with seed storage protein genes).
8. Seed oil modification, (developed by controlling chain length and saturation with fatty acid synthesis genes including stearoyl-ACP desaturase, oleoyl-ACP thioesterase, β -ketoacyl-ACP synthase and acyl-ACP thioesterase).
9. Delayed ripening of fruits, (developed by controlling ethylene producing genes, ACC oxidase gene).
10. Male sterility.
11. Modification of carbohydrate (developed with anti-sense gene of granule bound starch synthase, branching enzyme encoding genes, glgB).
12. Protein/peptides controlling human disease (Therapeutic peptides, proteins such as RMP-7, AC137, antithrombin hirudin, growth hormone, interleukin could be produced in plant-based system) to name a few examples.

The above heterologous genes, and other heterologous genes may be inserted into plasmids pKLP6 and pKLP36 by genetic engineering methods known in the art. These newly created germplasms can enhance breeding programs for crop improvement, as well providing as a better understanding of gene regulation and organization in transgenic plants. Plant metabolic engineering is the application of genetic engineering methods to modify the nature of chemical metabolites in plants. For metabolic engineering where multiple genes need to be inserted into one cell, the use of different, strong, constitutive promoters is desirable in order to avoid genetic instability caused by recombination between identical or closely related promoter sequences taken from plants them-

selves. Through use of the promoter sequences of the invention the introduced genes can be transcribed to messenger RNA and then RNA translated to resultant proteins that exhibit new traits or characters. The invention described herein, in developing gene vectors with newly defined promoters of the caulimoviruses, advances this effort.

A wide variety of well-characterized genes of animal, human, bacterial and of plant origin, including those of several viruses, are available for engineering plants. For the most effective expression of this wide selection of genes either constitutive or regulated, versatile gene expression vectors are required.

EXAMPLE 3

Comparative functional analysis of the CaMV35S and the FMV FLt promoters in transient expression experiments using tobacco leaf protoplasts:

In earlier studies (Maiti, et al., 1996) the relative strengths of the CaMV 35S and the FMV FLt promoters were compared. Different vector constructs with the GUS gene in transient expression experiments in protoplasts of *Nicotiana edwardsonii* were tested. Later the expression of the FMV FLt promoter with the PCISV FLt promoter in transgenic plants was compared (see example 2).

Isolation of protoplasts from *Nicotiana edwardsonii* cell suspension cultures and electroporation of protoplasts with supercoiled plasmid DNA containing GUS has been described (Gowda et al., 1989; Kiernan et al., 1993). Fluorometric GUS assays to measure GUS activity of plant tissue extracts and histochemical GUS assays to determine the distribution of GUS activity in plants, embryos and seedlings, were performed according to published procedures (Jefferson et al., 1987). Protein in plant extracts was estimated (Bradford 1976) using BSA as a standard. The fluorometric GUS assays was performed as described earlier (Maiti et al., 1996).

The results from the transient expression experiments are shown in Table 1. The gene constructs with the wild-type FLt promoter (pFMV 20 GUS) with its single enhancer domain showed about 2.5 fold higher promoter activity than the CaMV 35S promoter-GUS construct (pGG1) in these assays. A control plasmid pc-GUS (CaMV 35S promoter-GUS-nos 3' terminator) contains an extra out of frame ATG codon (as Sph I site GCATGC) in the multiple cloning site of pKYLX 7. The presence of this ATG codon causes about 7-8 fold less GUS activity compared to pGG1. The duplication of FMV FLt promoter enhancer domain in plasmid pKLF2-GUS increased the level of GUS activity about 4 fold as compared to pKLF-GUS with the single enhancer domain. This difference was also observed in a stably transformed system in intact tobacco plants (Maiti, et al., 1996).

EXAMPLE 4

Comparative functional analysis of FMV and PCISV FLt promoters in transgenic plants

The constructs shown in FIG. 6 were introduced into tobacco plants via the Agrobacterium co-cultivation method as described earlier (Maiti et al., 1988). Transformations were done using *Nicotiana tabacum* cv Samsun NN. Primary transformants of tobacco were selected for resistance to kanamycin (300 mg/ml) and these were grown to maturity in the greenhouse. At least 8-10 independent lines were generated for each construct tested. The expression levels of the GUS reporter gene in independent transformants developed for pKLP6GUS, pKLP36GUS are shown in FIG. 7. The expression from the PCISV FLt promoter was compared with that from the FMV promoter.

Individual plant lines generated from independent calli expressing the same gene showed variable GUS activity. Similar patterns of plant-to-plant variations in gene expression have been reported with many other plant promoters as pointed out earlier (Maiti et al., 1996). Most of the plant lines developed with pKLF36GUS showed more activity than any of the plants transformed with pKLP6GUS. On average, about 3 fold higher activity was exhibited by plants transformed with pKLP36GUS, which has a duplicated enhancer domain as compared to plants transformed with pKLP6GUS which has a single enhancer domain. Hence, the PCISV FLt promoter with a duplicated enhancer domain is more active than the FLt promoter with a single enhancer domain. These constitutive promoters developed from PCISV and FMV FLt promoter were comparable in respect to expression of reporter genes in transgenic plants.

EXAMPLE 5

Expression levels in seedlings (R1 progeny) and young tobacco plants

In order to examine the promoter activity in various tissues during seedling development, the expression of the GUS reporter gene in seedlings (R1 progeny) transformed with pKLP6GUS, or pKLP36GUS was examined by fluro-metric assay of tissue extracts and by histochemical staining of transverse sections of leaves, stems and roots. The PCISV promoter activity was monitored in 15 day old seedlings grown aseptically on an MS-agar medium in the presence of kanamycin (300 µg/ml) and 3% sucrose. Several independent lines for each construct were studied.

Comparison of activities of the FLt promoter indicated a gradient of expression in the following order; the highest level of activity was found in roots followed by leaves and stems. The histochemical staining shown in FIG. 8 is representative of the staining patterns analyzed in plants expressing high levels of GUS activity. In seedlings and sections of young leaves stained for GUS, the intensity of staining was markedly greater in vascular tissues of young leaves, petioles, stems and roots.

The intensity of GUS staining observed in vascular tissue was in the following order: roots>leaves>stems (FIG. 8). The histochemical GUS assay in leaves showed more activity in midribs, veins and other vascular tissue, and in trichomes, than in leaf mesophyll and palisade cells (data not shown). No GUS activity was detected in transgenic plants containing the construct pKLP36CAT gene (FIG. 8A).

The disarmed Agrobacterium strain transformed with plant expression vectors containing chimeric genes of interest can be used to engineer plants including but not limited to cotton, soybean, alfalfa, oilseed rape, flax, tomato, sugar beet, sunflower, potato, tobacco, maize, wheat, rice and lettuce, banana. The use of DNA fragments or vectors including the PCISV promoter sequence tailored with heterologous DNA sequence in the transformation of plants by electroporation or particle gun transformation is within the scope of this invention. These embodiments and examples are provided in order to evaluate the practice of the present invention. These examples serve mainly illustrative purposes, and are not intended to limit the scope of the invention.

TABLE 1

Constructs	Relative GUS activity (%)
Control (TE buffer)	00
pUC8 GUS (No promoter)	00
pc-GUS (extra ATG)	7
PGG1 (CaMV35S)	35
pFMV 20-GUS (FMV FLt)	100
pKLF (FMV FLt modified)	100
pKLF 2 (2 × Enh FMV FLt)	410

Table 1: Relative β-glucuronidase (GUS) activity of GUS fusion constructs containing different promoters electropo-rated into tobacco protoplasts. The GUS assay was carried out 20 hrs after electroporation. Assays and conditions were as described in the Methods. Promoter strength is presented as percentage of GUS activity normalized to pFMV 20 GUS for pUC based constructs or pKLFGUS for pKYLX7 based constructs, and represent the mean of three samples from at least two independent experiments, variation was within 12% of the presented value.

FIG. 7 shows a comparison of the FMV promoter with the PCISV. These results suggest that expression of the FMV and PCISV are comparable and that the PCISV promoter is stronger than the CaMV promoter.

DETAILED DESCRIPTION OF THE FIGURES

FIG. 1. The DNA sequence of the full-length transcript promoter from the peanut chlorotic caulimovirus, (PCISV), (Richins et al., 1993). The nucleotide sequence (PCISV coordinates 5799 to 6150, a 352 bp fragment) includes the 3' end of gene VI (SEQ ID NO:1), and part of the large intergenic region, presented from left to right in the 5' to 3' direction of the transcript. The TATA box, CCACT box are shown in bold. The transcription initiation site for the full-length FMV transcript is indicated as +1, (position 6078). Repeat sequence domains (1a, 1b; to 6a, 6b as indicated) are under lined or overlined. These sequence motif may be important for the promoter function.

FIGS. 2A and 2B show a construction strategy of PCISV FLt promoter with its single and double enhancer domains. Number in parenthesis indicate nucleotide position in PCISV genome. MCS, multiple cloning sites

FIG. 3. Physical map of pKYLX71.

FIG. 4. Physical map of pKLP6; MCS, multiple cloning sites.

FIG. 5. Physical map of pKLP36; MCS, multiple cloning sites FIG. 6. Schematic representation of chimeric GUS constructs used for assaying PCISVFLt promoter expression activity in transgenic plants. The identity of the respective promoter is shown for each plasmid. GUS represents the gene for β-glucuronidase of *E. coli*. The position of restriction sites XhoI, SacI, EcoRI, HindIII, ClaI used to assemble these plasmids are shown. The position of the left and right T-DNA borders (LB and RB respectively) the rbcS polyadenylation signal (3' REGION) and the Kmr gene are illustrated. NT3' or RT3' represent the polyadenylation sequences from NOS or RbcS gene respectively.

FIG. 7. PCISV FLt promoter activity in transgenic plants expressing GUS reporter gene. Comparative analysis of the

PCISV FLt promoter activity in independent transgenic plants *Nicotiana tabacum* cv Samsun NN (2 week old seedlings, R1 progeny/second generation) expressing a GUS reporter gene. Independent transgenic lines were developed with PCISV FLt promoter in construct pKLP6GUS containing a single enhancer domain, and in construct pKLP36GUS containing a double enhancer domains. Seeds obtained from transgenic plants were germinated in presence of kanamycin (200 µg/ml). GUS activity was determined in tissue extracts from whole seedlings. Independent plants were developed for constructs pKLP6GUS line # 1, 2, 5, 6, 19, 20, 21, and 22; and for construct pKLP36 line # 3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17 and 18. (C) Negative control, tissue extract from Samsun NN (wt). Positive control, one of the best expressing lines either from (T1) pKLF GUS line #11 with FMV FLt promoter with single enhancer domain or (T2) pKLF2GUS line #12 with double enhancer domain compared with PCISV FLt promoter. GUS activity are presented as % activity of the best expressing pKLF2GUS#12 line with FMV FLt double enhancer domain. The presented data is the mean of three samples from at least two independent experiments, variation was within 10% of the presented value.

FIG. 8. Histochemical localization of GUS activity in developing transgenic tobacco.

- A. Transgenic tobacco seedlings (X4), (pKLP36CAT, R1 progeny) with CAT gene, no GUS activity was detected.
- B. Seedling (X4), (pKLP6 GUS #21, R1 progeny) 14DAI; GUS activity was localized in root and leaves.
- C. Seedling (X4), (pKLP36 GUS #3, R1 progeny) 14DAI; GUS activity was localized in roots, roots hairs and leaves.
- D. Roots (3X) from six week old plants pKLP36CAT, R1 progeny, no GUS activity was detected.
- E. Roots (3X) from six week old plants pKLP6GUS #21, R1 progeny, GUS activity was detected in roots.
- F. Roots (X3) from six week old plants pKLP36GUS #3, R1 progeny, GUS activity was detected in roots.

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The purpose of the above description and examples is to illustrate some embodiments of the present invention without implying any limitation. It will be apparent to those of skill in the art that various modifications and variations may be made to the composition and method of the present invention without departing from the spirit or scope of the invention. All patents and publications cited herein are incorporated by reference in their entireties.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

(i i i) NUMBER OF SEQUENCES: 3

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 352 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(i i) MOLECULE TYPE: DNA (genomic)

(i i i) HYPOTHETICAL: NO

(i v) ANTI-SENSE: NO

-continued

(x i) SEQUENCE DESCRIPTION: SEQ ID NO:1:									
ACAGAGGGAT	TTCTCTGAAG	ATCATGTTTG	CCAGCTATGC	GAACAATCAT	CGGGAGATCT				6 0
TGAGCCAATC	AAAGAGGAGT	GATGTAGACC	TAAAGCAATA	ATGGAGCCAT	GACGTAAGGG				1 2 0
CTTACGCCAT	TACGAAATAA	TTAAAGGCTG	ATGTGACCTG	TCGGTCTCTC	AGAACCTTTA				1 8 0
CTTTTTATAT	TTGGCGTGTA	TTTTTAAATT	TCCACGGCAA	TGACGATGTG	ACCTGTGCAT				2 4 0
CCGCTTTGCC	TATAAATAAG	TTTTAGTTTG	TATTGATCGA	CACGATCGAG	AAGACACGGC				3 0 0
CATTTGGACG	ATCATTTGAG	AGTCTAAAAG	AACGAGTCTT	GTAATATGTT	TT				3 5 2
(2) INFORMATION FOR SEQ ID NO:2:									
(i) SEQUENCE CHARACTERISTICS:									
(A) LENGTH: 150 base pairs									
(B) TYPE: nucleic acid									
(C) STRANDEDNESS: single									
(D) TOPOLOGY: linear									
(i i) MOLECULE TYPE: DNA (genomic)									
(i i i) HYPOTHETICAL: NO									
(i v) ANTI-SENSE: NO									
(x i) SEQUENCE DESCRIPTION: SEQ ID NO:2:									
GAGATCTTGA	GCCAATCAAA	GAGGAGTGAT	GTAGACCTAA	AGCAATAATG	GAGCCATGAC				6 0
GTAAGGGCTT	ACGCCATTAC	GAAATAATTA	AAGGCTGATG	TGACCTGTCG	GTCTCTCAGA				1 2 0
ACCTTTACTT	TTTATATTTG	GCGTGTATTT							1 5 0
(2) INFORMATION FOR SEQ ID NO:3:									
(i) SEQUENCE CHARACTERISTICS:									
(A) LENGTH: 78 base pairs									
(B) TYPE: nucleic acid									
(C) STRANDEDNESS: single									
(D) TOPOLOGY: linear									
(i i) MOLECULE TYPE: DNA (genomic)									
(i i i) HYPOTHETICAL: NO									
(i v) ANTI-SENSE: NO									
(x i) SEQUENCE DESCRIPTION: SEQ ID NO:3:									
GAGATCTTGA	GCCAATCAAA	GAGGAGTGAT	GTAGACCTAA	AGCAATAATG	GAGCCATGAC				6 0
GTAAGGGCTT	ACGCCATT								7 8

- We claim:
1. A DNA construct comprising a full-length transcript promoter from peanut chlorotic streak virus, at least one enhancer domain from peanut chlorotic streak virus, a heterologous gene and border regions from *Agrobacterium tumefaciens*, wherein said promoter is operably linked to said heterologous gene.
 2. The DNA construct of claim 1, wherein said at least one enhancer domain is a single enhancer domain.
 3. The DNA construct of claim 1, wherein said at least one enhancer domain is a double enhancer domain.
 4. The DNA construct of claim 1, wherein said promoter comprises the nucleotide sequence of SEQ ID NO:1.
 5. The DNA construct of claim 1, having the designation pKLP6 or pKLP36, which is transformed in *Escherichia coli* and deposited as Accession No. NRRL B-21604 or Accession No. NRRL B-21605.
 6. The DNA construct of claim 1, further comprising a non-translated leader sequence from peanut chlorotic streak virus.
 7. A microorganism transformed with the DNA construct of claim 1.
 8. The microorganism of claim 7, which is *Escherichia coli*.
 9. The microorganism of claim 8, having Accession No. NRRL B-21604 or Accession No. NRRL B-21605.
 10. A plant cell transformed with the DNA construct of claim 1.
 11. The plant cell of claim 10, wherein said at least one enhancer domain of said DNA construct is a double enhancer domain.
 12. The plant cell of claim 10, which is a cell from a plant selected from the group consisting of cotton, soybean, alfalfa, oilseed rape, flax, tomato, sugar beet, sunflower, potato, tobacco, maize, wheat, rice, lettuce and banana.

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- 13. The plant cell of claim 2, which is a tobacco cell.
- 14. The plant cell of claim 10, which is from a tissue selected from the group consisting of calyx, filament, pedicel, style, ovary, corolla, anther, stigma, leaf, seed, embryo, stem and root.
- 15. A plant transformed with the DNA construct of claim 1.

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- 16. The plant of claim 15, which is selected from the group consisting of cotton, soybean, alfalfa, oilseed rape, flax, tomato, sugar beet, sunflower, potato, tobacco, maize, wheat, rice, lettuce and banana.
- 17. The plant of claim 16 which is tobacco.

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