



DESCRIPTION

GENES CODING FOR FLAVONE SYNTHASES

Technical Field

5 The present invention relates to the control and
utilization of biosynthesis of flavones, which have
effects on flower color, protection from ultraviolet ray,
symbiosis with microorganisms, etc. in plants, by a
genetic engineering technique. More specifically, it
10 relates to genes encoding proteins with activity of
synthesizing flavones from flavanones, and to their
utilization.

Background Art

15 The abundance of different flower colors is one of
the pleasant aspects of life that enriches human minds
and hearts. It is expected to increase food production
to meet future population increase by the means of
accelerating the growth of plants through symbiosis with
microorganisms, or by increasing the number of nitrogen-
20 fixing leguminous bacteria, thus improving the plant
productivity as a result of increasing the content of
nitrogen in the soil. Elimination or reduction of the
use of agricultural chemicals is also desirable to
achieve more environmentally friendly agriculture, and
25 this requires improvement of the soil by the above-
mentioned biological means, as well as higher resistance
of plants against microbial infection. Another desired
goal is to obtain plants with high protective functions
against ultraviolet rays as a means of protecting the
30 plants from the destruction of the ozone layer.

 "Flavonoid" is a general term for a group of
compounds with a C6-C3-C6 carbon skeleton, and they are
widely distributed throughout plant cells. Flavonoids
are known to have such functions as attracting insects
35 and other pollinators, protecting plant from ultraviolet
rays, and participating in interaction with soil
microorganisms (BioEssays, 16 (1994), Koes et al., p.123;



Trends in Plant Science, 1 (1997), Shirley, B.W., p.377).

Of flavonoids, flavone plays an important role in interaction of plants with microorganisms, especially in legumes, where they participate in the initial steps of the symbiosis with leguminous bacteria (Plant Cell, 7 (1995), Dixon and Paiva, p.1085; Annu. Rev. Phytopathol., 33 (1995), Spaink, p.345). Flavones in petals play a role in recognition by insects and act as copigments which form complexes with anthocyanins. (Gendai Kagaku, (May, 1998), Honda and Saito, p.25; Prog. Chem. Org. Natl. Prod., 52 (1987), Goto, T., p.114). It is known that when flavone forms a complex with anthocyanin, the absorption maximum of the anthocyanin shifts toward the longer wavelength, i.e. toward blue.

The biosynthesis pathways for flavonoids have been widely studied (Plant Cell, 7 (1995), Holton and Cornish, p.1071), and the genes for all of the enzymes involved in the biosynthesis of anthocyanidin 3-glucoside and flavonol, for example, have been isolated. However, the genes involved in the biosynthesis of flavones have not yet been isolated. The enzymes that synthesize flavones include those belonging to the dioxygenase family that depends on 2-oxoglutaric acid (flavone synthase I) and monooxygenase enzymes belonging to the cytochrome P450 family (flavone synthase II). These groups of enzymes are completely different enzymes with no structural homology.

It has been reported that in parsley, 2-oxoglutaric acid-dependent dioxygenase catalyzes a reaction which produces apigenin, a flavone, from naringenin, a flavanone (Z. Naturforsch., 36c (1981), Britsch et al., p.742; Arch. Biochem. Biophys., 282 (1990), Britsch, p.152). The other type, flavone synthase II, is known to exist in snapdragon (Z. Naturforsch., 36c (1981), Stotz and Forkmann, p.737) and soybean (Z. Naturforsch., 42c (1987), Kochs and Grisebach, p.343; Planta, 171 (1987), Kochs et al., p.519). A correlation has been recently

reported between a gene locus and flavone synthase II activity in the petals of gerbera (Phytochemistry, 49 (1998), Martens and Forkmann, p.1953). However, there are no reports that the genes for these flavone synthases I and II were isolated or that flavone synthase II was highly purified.

The properties of a cytochrome P450 protein, which had licodione-synthesizing activity that was induced when cultured cells of licorice (*Glycyrrhiza echinata*) were treated with an elicitor, were investigated. The protein is believed to catalyze the hydroxylation of 2-position of liquiritigenin which is a 5-deoxyflavanone, followed by non-enzymatic hemiacetal ring opening to produce licodione (Plant Physiol., 105 (1994), Otani et al., p.1427). For cloning of licodione synthase, a cDNA library was prepared from elicitor-treated *Glycyrrhiza* cultured cells, and 8 gene fragments encoding cytochrome P450 were cloned (Plant Science, 126 (1997), Akashi et al., p.39).

From these fragments there were obtained two different full-length cDNA sequences, each encoding a cytochrome P450, which had been unknown until that time. Specifically, they were CYPGe-3 (cytochrome P450 No.CYP81E1) and CYPGe-5 (cytochrome P450 No.CYP93B1, hereinafter indicated as CYP93B1) (Plant Physiol., 115 (1997), Akashi et al., p.1288). By further expressing the CYP93B1 cDNA in a system using cultured insect cells, the protein derived from the gene was shown to catalyze the reaction synthesizing licodione from liquiritigenin, a flavanone, and 2-hydroxynaringenin from naringenin, also a flavanone.

2-Hydroxynaringenin was converted to apigenin, a flavone, by acid treatment with 10% hydrochloric acid (room temperature, 2 hours). Also, eriodictyol was converted to luteolin, a flavone, by reacting eriodictyol with microsomes of CYP93B1-expressing yeast followed by acid treatment. It was therefore demonstrated that the

cytochrome P450 gene encodes the function of flavanone 2-hydroxylase activity (FEBS Lett., 431 (1998), Akashi et al., p.287). Here, production of apigenin from naringenin required CYP93B1 as well as another unknown enzyme, so that it was concluded that a total of two enzymes were necessary.

However, no genes have yet been identified for enzymes with activity of synthesizing flavones (such as apigenin) directly from flavanones (such as naringenin) without acid treatment. Thus, despite the fact that flavones have numerous functions in plants, no techniques have yet been reported for controlling their biosynthesis in plants, and improving the biofunctions in which flavones are involved, such as flower color. The discovery of an enzyme which by itself can accomplish synthesis of flavones from flavanones and acquisition of its gene, and introduction of such a gene into plants, would be more practical and industrially applicable than the introduction into a plant of genes for two enzymes involved in the synthesis of flavones from flavanones.

Disclosure of the Invention

It is an aim of the present invention to provide flavone synthase genes, preferably flavone synthase II genes, and more preferably genes for flavone synthases with activity of synthesizing flavones directly from flavanones. The obtained flavone synthase genes may be introduced into plants and over-expressed to alter flower colors.

Moreover, in the petals of flowers that naturally contain large amounts of flavones, it is expected that controlling expression of the flavone synthase genes by an antisense method or a cosuppression method can also alter flower colors. Also, expression of the flavone synthase genes in the appropriate organs, in light of the antibacterial activity of flavones and their interaction with soil microorganisms, will result in an increase in the antibacterial properties of plants and improvement in

the nitrogen fixing ability of legumes due to promoted symbiosis with rhizosphere microorganisms, as well as a protective effect against ultraviolet rays and light.

5 The present invention therefore provides genes encoding proteins that can synthesize flavones directly from flavanones. The genes are, specifically, genes encoding flavone synthase II that can synthesize flavones from flavanones by a single-enzyme reaction (hereinafter referred to as "flavone synthase II").

10 More specifically, the present invention provides genes encoding P450 proteins having the amino acid sequences listed as SEQ.ID. No. 2, 4 or 8 of the Sequence Listing and possessing activity of synthesizing flavones from flavanones, or genes encoding proteins having amino
15 acid sequences modified by additions or deletions of one or more amino acids and/or a substitution with different amino acids in said amino acid sequence, and possessing activity of synthesizing flavones from flavanones.

20 The invention further provides a gene encoding proteins having amino acid sequences with at least 55% identity with the amino acid sequences listed as SEQ.ID. No. 2, 4 or 8 of the Sequence Listing and possessing activity of synthesizing flavones from flavanones.

25 The invention still further provides genes encoding proteins possessing activity of synthesizing flavones from flavanones, and hybridizing with all or a part of the nucleotide sequences listed as SEQ.ID. No. 1, 3 or 7 of the Sequence List under the conditions of 5 x SSC, 50°C.

30 The invention still further provides a vector, particularly an expression vector, containing any one of the aforementioned genes.

The invention still further provides a host transformed with the aforementioned vector.

35 The invention still further provides a protein encoded by any of the aforementioned genes.

The invention still further provides a process for

producing the aforementioned protein which is characterized by culturing or growing the aforementioned host, and collecting the protein with flavone-synthesizing activity from the host.

5 The invention still further provides a plant into which any one of the aforementioned genes has been introduced, or progenies of the plant or a tissue thereof, such as cut flowers, which exhibit the same properties.

10 The invention still further provides a method of altering amounts and compositions of flavonoid using the aforementioned genes; a method of altering amounts of flavones using the aforementioned genes; a method of altering flower colors using the aforementioned genes; a
15 method of bluing the color of flowers using the aforementioned genes; a method of reddening the color of flowers using the aforementioned genes; a method of modifying the photosensitivity of plants using the
20 aforementioned genes; and a method of controlling the interaction between plants and microbes using the aforementioned genes.

Brief Description of the Drawings

Fig. 1 is a chromatogram showing the results of HPLC analysis of products obtained from a substrate,
25 naringenin, using proteins encoded by CYP93B1 and TFNS5.

A and B: Obtained by adding a crude enzyme fraction of CYP93B1-expressing yeast.

C and D: Obtained by adding a crude enzyme fraction of TFNS5-expressing yeast.

30 A and C: Direct products obtained by addition of enzyme fraction.

B: Products obtained by acid treatment after reaction of A.

35 D: Products obtained by acid treatment after reaction of C.

Embodiments for Carrying out the Invention

Flavanone 2-hydroxylase encoded by the *Glycyrrhiza*

CYP93B1 gene produces 2-hydroxyflavanones from flavanones as the substrates, and the products are converted to flavones by acid treatment. The present inventors viewed that it would be possible to obtain a gene encoding a
5 flavone synthase II, which was an object of the invention, by using the *Glycyrrhiza*-derived cDNA, CYP93B1 for screening of a cDNA library of, for example, a flower containing a large amount of flavones, to thus obtain cDNA encoding proteins with activity of synthesizing
10 flavones directly from flavanones as substrates.

According to the invention, a cDNA library of snapdragon which contains a large amount of flavones is screened using the *Glycyrrhiza*-derived cDNA, CYP93B1 as a probe, to obtain cDNA encoding a novel cytochrome P450
15 (see Example 1). The snapdragon cDNA, ANFNS2, obtained in this manner and the *Glycyrrhiza* CYP93B1 cDNA were then used as a mixed probe to obtain TFNS5, a cDNA encoding a novel cytochrome P450, from a cDNA library of *torenia* flower petals (see Example 2).

20 The *torenia*-derived cDNA was expressed in yeast and reacted with naringenin, a flavanone, as a substrate which resulted in production not of 2-hydroxynaringenin but rather of the flavone apigenin, without acid treatment (see Example 3). In other words, this enzyme
25 directly produced flavones from flavanones without acid treatment, and its gene was confirmed to be a flavone synthase II which had never been cloned. The amino acid sequence encoded by the snapdragon-derived ANFNS2 of Example 1 exhibited high identity of 77% with the flavone
30 synthase II encoded by TFNS5, and it exhibited the enzyme activity of flavone synthase II (Example 4). In addition, since an amino acid sequence encoded by perilla-derived cDNA also exhibited high identity of 76% and 75% with TFNS5 and ANFNS2, respectively (Example 8),
35 it is speculated that the protein encoded by this cDNA also possesses the same enzymatic activity as the flavone synthases encoded by TFNS5 and ANFNS2.

The genes of the present invention may be, for example, one encoding the amino acid sequences listed as SEQ.ID. No. 2, 4 or 8 of the Sequence Listing. However, it is known that proteins whose amino acid sequences are modified by additions or deletions of multiple amino acids and/or substitutions with different amino acids can maintain the same enzyme activity as the original protein. Consequently, proteins having the amino acid sequences listed as SEQ.ID. No. 2, 4 or 8 of the Sequence Listing wherein the amino acid sequence is modified by additions or deletions of one or more amino acids and/or substitutions with different amino acids, and genes encoding those proteins, are also encompassed by the present invention so long as they maintain the activity of producing flavones directly from flavanones.

The present invention also relates to genes that have the nucleotide sequences listed as SEQ.ID. Nos. 1, 3 and 7 and nucleotide sequences encoding the amino acid sequences listed therein, or that hybridize with portions of their nucleotide sequences under conditions of 5 x SSC, 50°C, for example, providing they encode proteins possessing activity of producing flavones from flavanones. The suitable hybridization temperature will differ depending on nucleotide sequences and the length of nucleotide sequences, and for example, when the probe used is a DNA fragment comprising 18 bases coding for 6 amino acids, the temperature is preferably not higher than 50°C.

A gene selected by such hybridization may be a naturally derived one, such as a plant-derived gene, for example, a gene derived from snapdragon, torenia or perilla; it may also be a gene from another plant, such as gentian, verbena, chrysanthemum, iris, or the like. A gene selected by hybridization may be cDNA or genomic DNA.

The invention also relates to genes encoding proteins that have amino acid sequences with identity of

at least 55%, preferably at least 70%, such as 80% or greater and even 90% or greater, with any one of the amino acid sequences listed as SEQ.ID. Nos. 2, 4 or 8 of the Sequence Listing, and that possess activity of synthesizing flavones from flavanones.

A gene with the natural nucleotide sequence can be obtained by screening of a cDNA library, for example, as demonstrated in detail in the examples. DNA encoding enzymes with modified amino acid sequences can be synthesized using common site-directed mutagenesis or a PCR method, using DNA with a natural nucleotide sequence as a starting material. For example, a DNA fragment into which a modification is to be introduced may be obtained by restriction enzyme treatments of natural cDNA or genomic DNA and then used as a template for site-directed mutagenesis or PCR using a primer having the desired mutation introduced therein, to obtain a DNA fragment having the desired modification introduced therein. Mutation-introduced DNA fragments may then be linked to a DNA fragment encoding another portion of a target enzyme.

Alternatively, in order to obtain DNA encoding an enzyme consisting of a shortened amino acid sequence, for example, DNA encoding an amino acid sequence which is longer than the aimed amino acid sequence, such as the full length amino acid sequence, may be cut with desired restriction endonucleases, and if the DNA fragment obtained thereby does not encode the entire target amino acid sequence, it may be linked with synthesized DNA comprising the rest of the sequence.

Thus obtained genes may be expressed in an expression system using *E. coli* or yeast and its enzyme activity measured to confirm that the obtained gene encodes flavone synthase. By expressing the gene, it is also possible to obtain the flavone synthase protein as the gene product. Alternatively, it is also possible to obtain a flavone synthase protein even using antibodies for a full or a partial amino acid sequence listed as

SEQ.ID. No. 2, 4 or 8, and such antibodies may be used for cloning of a flavone synthase gene in another organism.

Consequently, the invention also relates to
5 recombinant vectors, and especially expression vectors, containing the aforementioned genes, and to hosts transformed by these vectors. The hosts used may be prokaryotic or eukaryotic organisms. Examples of
10 prokaryotic organisms that may commonly be used as hosts include bacteria belonging to the genus *Escherichia*, such as *Escherichia coli*, and microorganisms belonging to the genus *Bacillus*, such as *Bacillus subtilis*.

Examples of eukaryotic hosts that may be used include lower eukaryotic organisms, for example,
15 eukaryotic microorganisms, for example, Eumycota such as yeast and filamentous fungi. As yeast there may be mentioned microorganisms belonging to the genus *Saccharomyces*, such as *Saccharomyces cerevisiae*, and as filamentous fungi there may be mentioned microorganisms
20 belonging to the genus *Aspergillus*, such as *Aspergillus oryzae* and *Aspergillus niger* and microorganisms belonging to the genus *Penicillium*. Animal cells and plant cells may also be used, the animal cells being cell lines from mice, hamsters, monkeys or humans. Insect cells, such as
25 silkworm cells, or the adult silkworms themselves, may also be used.

The expression vectors of the invention will include expression regulating regions such as a promoter and a terminator, a replication origin, etc., depending on the
30 type of hosts into which they are to be introduced. Examples of promoters for bacterial expression vectors which may be used include conventional promoters such as trc promoter, tac promoter, lac promoter, etc., examples of yeast promoters that may be used include
35 glyceraldehyde-3-phosphate dehydrogenase promoter, PH05 promoter, etc., and examples of filamentous fungi promoters that may be used include amylase promoter,

trpC, etc. Examples of animal cell host promoters that may be used include viral promoters such as SV40 early promoter, SV40 late promoter, etc.

5 The expression vector may be prepared according to a conventional method using restriction endonucleases, ligases and the like. The transformation of a host with an expression vector may also be carried out according to conventional methods.

10 The hosts transformed by the expression vector may be cultured, cultivated or raised, and the target protein may be recovered and purified from the cultured product, etc. according to conventional methods such as filtration, centrifugal separation, cell crushing, gel filtration chromatography, ion-exchange chromatography
15 and the like.

The present specification throughout discusses flavone synthases II derived from snapdragon, torenia and perilla that are capable of synthesizing flavones directly from flavanones, and it is also known that the
20 cytochrome P450 genes constitute a superfamily (DNA and Cell Biology, 12 (1993), Nelson et al., p.1) and that cytochrome P450 proteins within the same family have 40% or greater identity in their amino acid sequences while cytochrome P450 proteins within a subfamily have 55% or
25 greater identity in their amino acid sequences, and their genes hybridize to each other (Pharmacogenetics, 6 (1996), Nelson et al., p.1).

For example, a gene for flavonoid 3',5'-hydroxylase, which was a type of cytochrome P450 and participated in
30 the pathway of flavonoid synthesis, was first isolated from petunias (Nature, 366 (1993), Holton et al., p.276), and the petunia flavonoid 3',5'-hydroxylase gene was used as a probe to easily isolate a flavonoid 3',5'-hydroxylase gene from gentian (Plant Cell Physiol., 37
35 (1996), Tanaka et al., p.711), prairie-gentian, bellflower (WO93/18155 (1993), Kikuchi et al.), lavender, torenia and verbena (Shokubutsu no Kagaku Chosetsu, 33

(1998), Tanaka et al., p.55).

Thus, a part or all of any of the flavone synthase II genes of the invention derived from snapdragon, torenia or perilla, which are capable of synthesizing flavones directly from flavanones, can be used as a probe, in order to obtain flavone synthase II genes capable of synthesizing flavones directly from flavanones, from different species of plants. Furthermore, by purifying the snapdragon-, torenia- or perilla-derived flavone synthase II enzymes described in this specification which can synthesize flavones directly from flavanones, and obtaining antibodies against the enzymes by conventional methods, it is possible to obtain different flavone synthase II proteins that react with the antibodies, and obtain genes coding for those proteins.

Consequently, the present invention is not limited merely to snapdragon-, torenia- or perilla-derived genes for flavone synthases II capable of synthesizing flavones directly from flavanones, but further relates to flavone synthases II derived from numerous other plants, which are capable of synthesizing flavones directly from flavanones. The sources for such flavone synthase II genes may be, in addition to snapdragon, torenia and perilla described here, also gentian, verbena, chrysanthemum, iris, commelina, centaurea, salvia, nemophila and the like, although the scope of the invention is not limited to these plants.

The invention still further relates to plants whose colors are modified by introducing a gene or genes for flavone synthases II that can synthesize flavones directly from flavanones, and to progenies of the plants or their tissues, which may also be in the form of cut flowers. By using the flavone synthases II or their genes which have been cloned according to the invention, it is possible to produce flavones in plant species or varieties that otherwise produce little or absolutely no

flavones. By expressing the flavone synthase II gene or the genes in flower petals, it is possible to increase the amount of flavones in the flower petals, thus allowing the colors of the flowers to be modified toward the blue, for example.

Conversely, by repressing synthesis of flavones in flower petals, it is possible to modify the colors of the flowers toward the red, for example. However, flavones have myriad effects on flower colors, and the changes in flower colors are therefore not limited to those mentioned here. With the current level of technology, it is possible to introduce a gene into a plant and express the gene in a constitutive or tissue-specific manner, while it is also possible to repress the expression of a target gene by an antisense method or a cosuppression method.

As examples of transformable plants there may be mentioned rose, chrysanthemum, carnation, snapdragon, cyclamen, orchid, prairie-gentian, freesia, gerbera, gladiolus, baby's breath, kalanchoe, lily, pelargonium, geranium, petunia, torenia, tulip, rice, barley, wheat, rapeseed, potato, tomato, poplar, banana, eucalyptus, sweet potato, soybean, alfalfa, lupin, corn, etc., but there is no limitation to these.

Because flavones have various physiological activities as explained above, they can impart new physiological activity or economic value to plants. For example, by expressing the gene to produce flavones in roots, it is possible to promote growth of microorganisms that are beneficial for the plant, and thus promote growth of the plant. It is also possible to synthesize flavones that exhibit physiological activity in humans, animals or insects.

35 Examples

The invention will now be explained in further detail by way of the following examples. Unless

otherwise specified, the molecular biological methods were carried out according to Molecular Cloning (Sambrook et al., 1989).

Example 1. Cloning of snapdragon flavone synthase II gene

5 RNA was extracted from about 5 g of young buds of a Yellow Butterfly snapdragon (commercial name by Sakata-no-Tane, KK.), and polyA⁺ RNA was obtained by an Oligotex. This polyA⁺ RNA was used as a template to
10 prepare a cDNA library using a Lambda ZAPII cDNA Library Synthesis Kit (Stratagene) by the method recommended by Stratagene (Stratagene Instruction Manual, Revision #065001). The cDNA library was screened using the full length cDNA CYP93B1 as the probe. The screening and
15 detection of positive clones were carried out using a DIG-DNA-labeling and detection kit (Boehringer) based on the method recommended by the same company, under a low stringent condition.

Specifically, a hybridization buffer (5 x SSC, 30%
20 formamide, 50 mM sodium phosphate buffer (pH 7.0), 1% SDS, 2% blocking reagent (Boehringer), 0.1% lauroylsarcosine, 80 µg/ml salmon sperm DNA) was used for prehybridization at 42°C for 2 hours, after which the DIG-labeled probe was added and the mixture was kept
25 overnight. The membrane was rinsed in 5 x SSC rinsing solution containing 1% SDS at 65°C for 1.5 hours. One positive clone was obtained, and it was designated as ANFNS1. Upon determining the nucleotide sequence at the
30 5' end of ANFNS1 it was expected that ANFNS1 encodes a sequence with high identity with the flavanone 2-hydroxylase encoded by licorice CYP93B1, and it was assumed that it encoded a P450 with a function similar to that of flavanone 2-hydroxylase.

35 However, a comparison with the amino acid sequence of flavanone 2-hydroxylase encoded by CYP93B1 suggested that the cDNA of ANFNS1 is not a full-length cDNA, lacking the portion corresponding to approximately 65

amino acid residues from the initiating methionine. The ANFNS1 cDNA was therefore used as a probe for-rescreening of the snapdragon cDNA library, to obtain cDNA (ANFNS2) which was believed to include the full-length amino acid sequence. The protein encoded by ANFNS2 obtained here exhibited 53% identity on the amino acid level with flavanone 2-hydroxylase encoded by licorice CYP93B1.

The nucleotide sequence of ANFNS2 is listed as SEQ.ID. No.1, and the amino acid sequence deduced therefrom is listed as SEQ.ID. No.2.

Example 2. Cloning of torenia flavone synthase II gene

RNA was extracted from approximately 2 g of buds of a torenia variety (variety name: Sunrenive, Variety Registration Application No.: 7433 according to the Seeds and Seedlings Law, by Suntory Ltd.) and the polyA+ RNA was obtained with an Oligotex. The polyA+ RNA was used as a template to prepare a cDNA library using a Lambda ZAPII cDNA Library Synthesis Kit (Stratagene) by the method recommended by Stratagene as mentioned in Example 1. The cDNA library was screened using a mixture of the aforementioned CYP93B1 cDNA and ANFNS1 cDNA as the probes. The screening and detection of positive clones were carried out under the low stringent conditions as described in Example 1.

One positive clone was obtained, and was designated as TFNS5. Upon determining the full nucleotide sequence of TFNS5 cDNA, it was found that the protein encoded by TFNS5 cDNA exhibited 52% identity on the amino acid level with flavonone-2-hydroxylase encoded by licorice CYP93B1. This TFNS5 cDNA also had high identity of 77% with the protein encoded by ANFNS2, the snapdragon-derived cDNA obtained in Example 1. The determined nucleotide sequence is listed as SEQ.ID. No.3, and the amino acid sequence deduced therefrom is listed as SEQ.ID. No.4.

Example 3. Expression of torenia flavone synthase II
gene in yeast

The following experiment was conducted in order to detect the enzyme activity of the protein encoded by TFNS5, the torenia cDNA obtained in Example 2. Parts of the outside of the translated region of the gene were modified to introduce restriction enzyme sites therein to prepare a sense primer (5'-

AAATAGGATCCAAGCatgGACACAGTCTTAA-3'; underline = BamHI site; lowercase letters: initiation codon) (SEQ.ID. No.5) and an antisense primer (5'- CCCTTCTAGAtcaAGCACCCGATATTGTGGCCGGG-3'; underline = XbaI site; lowercase letters: termination codon) (SEQ.ID. No.6) were used with KOD polymerase (Toyobo) for PCR reaction. The PCR conditions were 98°C for one minute, 20 cycles of (98°C for 15 seconds, 55°C for 10 seconds, 74°C for 30 seconds), followed by 74°C for 10 minutes.

After introducing the resultant PCR product into the EcoRV site of pBluescriptII SK(-) (Stratagene), it was digested with restriction enzymes BamHI and XbaI and introduced at the BamHI-XbaI sites of the yeast expression vector pYES2 (Invitrogen). The resultant plasmid was then introduced into BJ2168 yeast (Nihon Gene). The enzyme activity was measured by the method described by Akashi et al. (FEBS Lett., 431 (1998), Akashi et al., p.287). The transformed yeast cells were cultured in 20 ml of selective medium (6.7 mg/ml amino acid-free yeast nitrogen base (Difco), 20 mg/ml glucose, 30 µg/ml leucine, 20 µg/ml tryptophan and 5 mg/ml casamino acid), at 30°C for 24 hours.

After harvesting the yeast cells with centrifugation, the harvested yeast cells were cultured at 30°C for 48 hours in an expressing medium (10 mg/ml yeast extract, 10 mg/ml peptone, 2 µg/ml hemin, 20 mg/ml galactose). After collecting the yeast cells, they were washed by suspending in water and collecting them. Glass beads were used for 10 minutes of disrupting, after which

the cells were centrifuged at 8000 x g for 10 minutes. The supernatant was further centrifuged at 15,000 x g for 10 minutes to obtain a crude enzyme fraction.

5 A mixture of 15 µg of (R,S)-naringenin (dissolved in 30 µl of 2-methoxyethanol), 1 ml of crude enzyme solution and 1 mM NADPH (total reaction mixture volume: 1.05 ml) was reacted at 30°C for 2 hours. After terminating the reaction by addition of 30 µl of acetic acid, 1 ml of ethyl acetate was added and mixed therewith. After 10 centrifugation, the ethyl acetate layer was dried with an evaporator. The residue was dissolved in 100 µl of methanol and analyzed by HPLC. The analysis was carried out according to the method described by Akashi et al. The acid treatment involved dissolution of the 15 evaporator-dried sample in 150 µl of ethanol containing 10% hydrochloric acid, and stirring for 30 minutes. This was diluted with 1.3 ml of water, 800 µl of ethyl acetate was further added and mixed therewith, and after centrifugation, the ethyl acetate layer was recovered. 20 This was then dried, dissolved in 200 µl of methanol, and analyzed by HPLC.

The yeast expressing licorice CYP93B1 produced 2-hydroxynaringenin from naringenin, but yielded no apigenin (Fig. 1, A). Only upon acid treatment of the 25 reaction mixture, apigenin was yielded from 2-hydroxynaringenin (Fig. 1, B). In contrast, the yeast expressing torenia TFNS5 yielded apigenin from naringenin without acid treatment of the reaction mixture (Fig. 1, C). This demonstrated that TFNS5 encodes a flavone 30 synthase II.

Example 4. Expression of snapdragon flavone synthase II gene in yeast

An approximately 1400 bp DNA fragment obtained by digesting ANFNS2 cDNA with BamHI and SphI, an 35 approximately 350 bp DNA fragment obtained by digesting the same with SphI and BamHI, and pYES2 digested with BamHI and XhoI were ligated to obtain a plasmid, which

was then introduced into yeast by the same method as described in Example 3. The resultant recombinant yeast cells were used to measure the flavone synthesis activity by the same method as in Example 3. The yeast expressing
5 the snapdragon-derived ANFNS2 produced apigenin without acid treatment, thus demonstrating that ANFNS2 encodes a flavone synthase II.

Example 5. Construction of expression vector in plants

A plant expression vector was constructed to
10 introduce TFNS5, the torenia cDNA obtained in Example 2, into plants. After digesting pBE2113-GUS (Plant Cell Physiol., 37 (1996), Mitsuhashi et al., p.49) with SacI, a blunting kit (Takara) was used to blunt the ends, after which a XhoI linker (Toyobo) was inserted. The resulting
15 plasmid was then digested with HindIII and EcoRI, and an approximately 3 kb DNA fragment was recovered. The DNA fragment was linked to the HindIII/EcoRI site of the binary vector pBINPLUS to prepare pBE2113'. Vector pBINPLUS used here was obtained by modifying the binary
20 vector Bin19 (Nucl. Acids Res., 12 (1984), Bevan, p.8711), which is widely used for gene introduction into plants using *Agrobacterium* cells, in the manner reported by van Engelen et al. (Transgenic Research, 4 (1995), van Engelen et al., p.288).

25 The TFNS5 cDNA was cut out of SK(-) vector by cleavage with BamHI/XhoI, and an approximately 1.7 kb fragment thus obtained was ligated to the BamHI/XhoI sites of the aforementioned binary vector pBE2113'. The construct thus obtained, pSPB441, expresses TFNS5 cDNA in
30 the sense direction under the control of 35S cauliflower mosaic virus promoter having a double repeat of the enhancer sequence (Plant cell Physiol., 37 (1996), Mitsuhashi et al., p.49).

Example 6. Alteration of torenia flower color

35 A torenia variety (variety name: Sunrenive, Variety Registration Application No.: 7433 according to the Seeds and Seedlings Law, by Suntory Ltd.) was transformed with

pSPB441 constructed in Example 5 above, according to the method of Aida et al. (Breeding Science, 45 (1995), Aida et al., p.71). Over 95% of the obtained transformants showed alteration of the flower color from the dark purple of the parent strain to a light purple. The left and the right flower petal colors of four flower petals were measured. While the flower petal color of the parent strain was Number 89A according to the Royal Horticultural Society Color Chart, the typical flower petal colors of the transformants were 82C, 87D, 87C, 88D, 91A, etc. These results indicated that introduction of TFNS5 into plants can alter flower colors.

In the transformed individuals, the amount of flavones ranged 1/5 to 1/10 that of the host, while the amount of anthocyanins was reduced to about 1/3 that of the host. Also detected were flavanones (naringenin, eriodictyol and pentahydroxyflavanone) which are flavone biosynthesis precursors that were not detected in the host.

Example 7. Expression of flavone synthase in petunias

Plasmid pSPB441 was introduced into a petunia variety (variety name: Revolution Violet Mini, Variety Registration Application No.: 9217, according to the Seeds and Seedlings Law, by Suntory Ltd.) according to the method of Napoli et al. (Plant Cell, 2, (1990), Napoli et al., p.279). Changes in flower colors occurred in two of the resultant transformants, where the flower colors were lighter than the parent strain. The flower color of the parent strain was Number 88A according to the Royal Horticultural Society Color Chart, whereas 87A in the transformants. Also, while no flavones were detected in the parent strain, a flavone, luteolin, was detected in the transformed strains.

Example 8. Cloning of perilla flavone synthase II gene

The method described in Example 1 was used to screen a cDNA library prepared from leaves of red perilla (*Perilla frutescens*) according to the method of Gong et

al. (Plant Mol. Biol., 35, (1997), Gong et al., p.915)
using λ gt10 (Stratagene) as the vector. Culturing, DNA
preparation and subcloning of the resulting phage clones
#3 were carried out according to the method of Gong et
5 al. (Plant Mol. Biol., 35, (1997), Gong et al., p.915),
and the nucleotide sequence was determined and listed as
SEQ.ID. No.7. The deduced amino acid sequence encoded by
this nucleotide sequence was listed as SEQ.ID. No.8.
This amino acid sequence showed 76% and 75% identity with
10 TFNS5 and ANFNS2, respectively. It also showed 52%
identity with CYP93B1.

Example 9. Expression of perilla flavone synthase II
gene in yeast

The phage clone #3 obtained in Example 8 was used as
15 a template for PCR by the method described in Example 3,
using Lambda Arm Primer (Stratagene). The amplified DNA
fragment was subcloned at the EcoRV site of pBluescript
KS(-). A clone with the initiation codon of perilla
flavone synthase II cDNA on the SalI site side of
20 pBluescript KS(-) was selected, and was designated as
pFS3. The nucleotide sequence of the cDNA insert of pFS3
was determined, and PCR was conducted to confirm the
absence of errors.

An approximately 1.8 kb DNA fragment obtained by
25 digesting pFS3 with SalI and XbaI was ligated with pYES2
digested with XhoI and XbaI (Example 3) to obtain a
plasmid which was designated as pYFS3, and this was
introduced into yeast BJ2168 by the method described in
Example 3. When the flavone synthase activity of this
30 recombinant yeast was measured by the method described in
Example 3, production of apigenin from naringenin was
confirmed, indicating that the perilla phage clone #3
cDNA encodes a protein with flavone synthase II activity.

Industrial Applicability

35 It is possible to alter flower colors by linking
cDNA of the invention to an appropriate plant expression
vector and introducing it into plants to express or

- inhibit expression of flavone synthases. Furthermore, by expressing the flavone synthase genes not only in petals but also in entire plants or their appropriate organs, it is possible to increase the resistance against
- 5 microorganisms of plants or to improve the nitrogen fixing ability of legumes by promoting association with rhizosphere microorganisms, as well as to improve the protective effects of plants against ultraviolet rays and light.

CLAIMS

1. An isolated gene encoding a flavone synthase II with activity of directly synthesizing flavones from flavanones.

2. An isolated gene according to claim 1 which encodes a protein having the amino acid sequence listed as SEQ.ID. No. 2, 4 or 8 of the Sequence Listing and showing activity of synthesizing flavones from flavanones, or an isolated gene encoding a protein having one of these amino acid sequences wherein the amino acid sequence has been modified by additions or deletions of one or more amino acids and/or one or more substitution with different amino acids, and possessing activity of synthesizing flavones from flavanones.

3. An isolated gene according to any one of claims 1 to 2, which has at least 55% identity with the amino acid sequence listed as SEQ.ID. No. 2, 4 or 8 of the Sequence Listing and possesses activity of synthesizing flavones from flavanones.

4. An isolated gene according to any one of claims 1 to 3, which hybridizes with all or a part of any one of the base sequence listed as SEQ.ID. No. 1, 3 and 7 of the Sequence Listing under conditions of 5 x SSC, 50°C, and which encodes a protein possessing activity of synthesizing flavones from flavanones.

5. A vector comprising an isolated gene according to any one of claims 1 to 4.

6. A host transformed by a vector according to claim 5.

7. A protein encoded by a gene according to any one of claims 1 to 4.

8. A method of producing a protein with flavone-synthesizing activity, which is characterized by culturing or growing a host according to claim 6 and recovering said protein from said host.

9. A plant into which a gene according to any one

of claims 1 to 4 has been introduced, or progenies of said plant or a tissue thereof, which exhibits the same properties.

5 10 . A cut flower from a plant or a progeny thereof having the same properties, according to claim 9 .

11 . A method of altering a composition flavonoids and/or its amount using a gene according to any one of claims 1 to 4 .

10 12 . A method of altering the amount of a flavone using a gene according to any one of claims 1 to 4 .

13 . A method of altering the color of a flower using a gene according to any one of claims 1 to 4 .

14 . A method of bluing the color of a flower using a gene according to any one of claims 1 to 4 .

15 15 . A method of reddening the color of a flower using a gene according to any one of claims 1 to 4 .

16 . A method of altering the photosensitivity of a plant using a gene according to any one of claims 1 to 4 .

20 17 . A method of controlling the interaction between a plant and microorganisms using a gene according to any one of claims 1 to 4 .