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(54) **NICOTIANAMINE SYNTHASE AND GENE ENCODING THE SAME**

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(51) **Int. Cl.**

C12N 9/10 (2006.01)
C12N 9/00 (2006.01)
C07K 1/00 (2006.01)
A01H 9/00 (2006.01)
A01H 5/00 (2006.01)

(52) **U.S. Cl.** **435/193**; 435/183; 530/350; 800/295; 800/320; 800/320.2

(58) **Field of Classification Search** 435/252.3, 435/320.1, 183, 193; 530/350; 800/295, 800/320, 320.2

See application file for complete search history.

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(57) **ABSTRACT**

A nicotianamine synthase is isolated and purified. Then the gene of this enzyme is cloned and the base sequence and amino acid sequence thereof are determined. This gene is employed in constructing plants, in particular, grass plants highly tolerant to iron deficiency. A nicotianamine synthase involved in the mugineic acid biosynthesis pathway; the amino acid sequence thereof; a gene encoding the same; a vector containing this gene; cells transformed by the vector; a process for producing nicotianamine by using the same; plants transformed by the gene encoding the nicotianamine synthase; and an antibody against the nicotianamine syntase.

8 Claims, 18 Drawing Sheets

Fig. 1

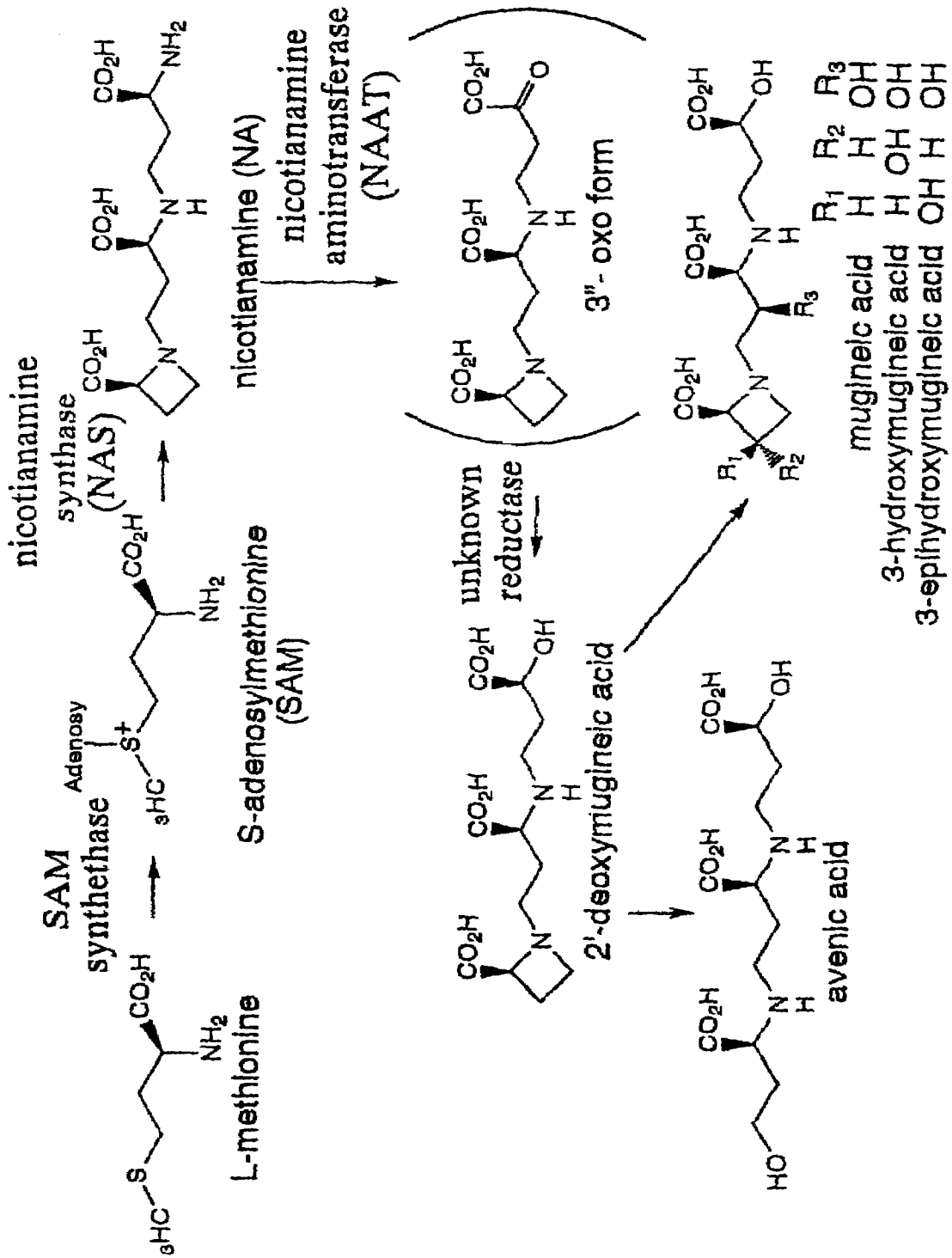


Fig. 2

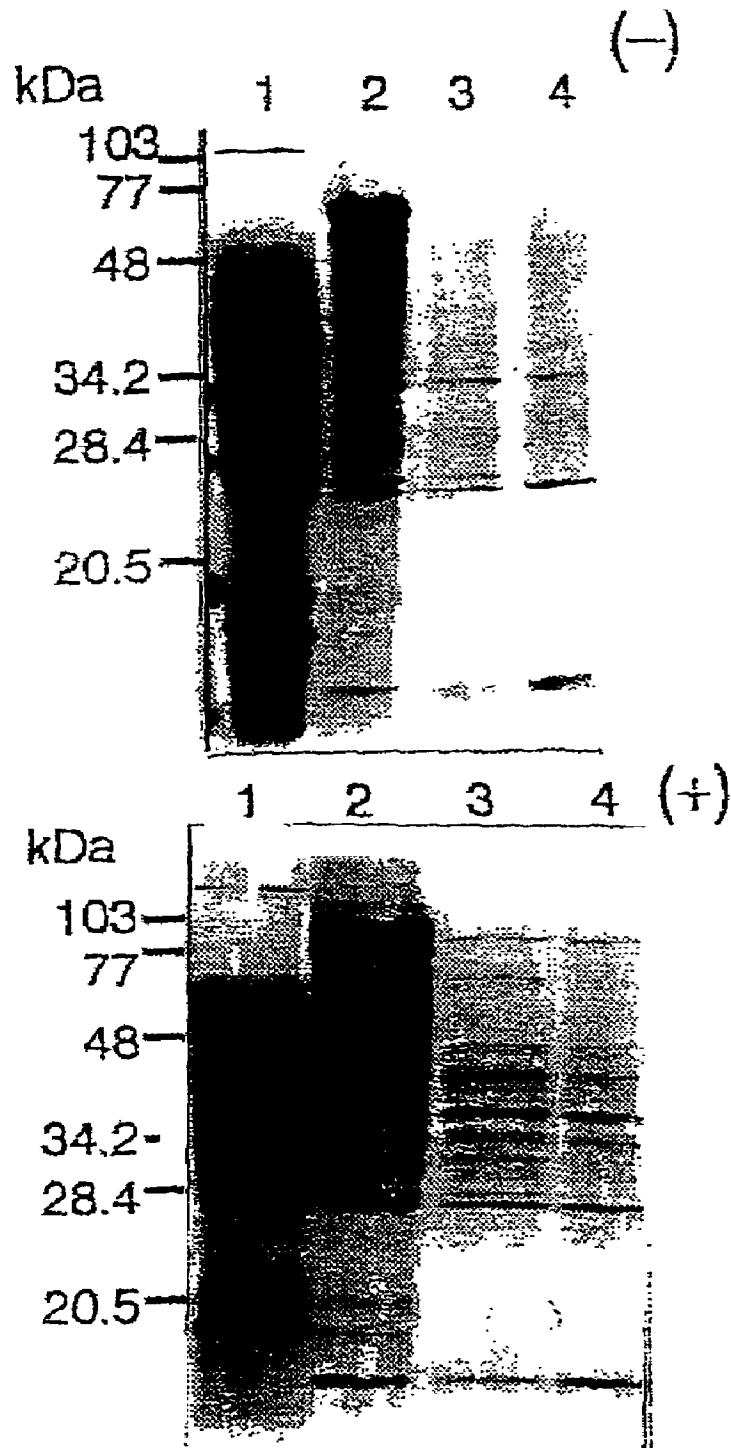


Fig. 3

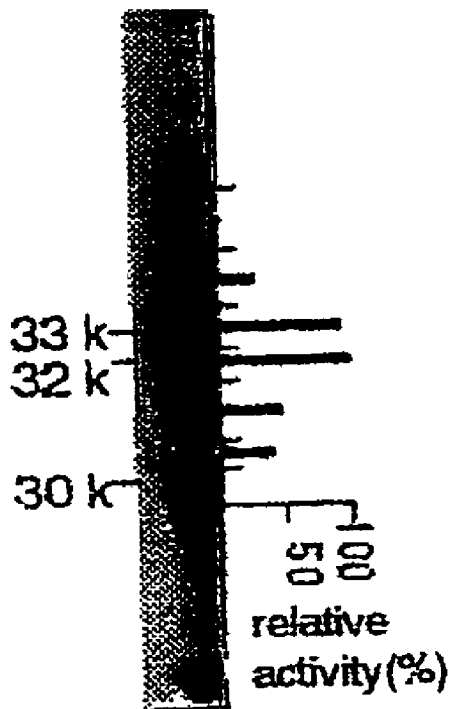


Fig. 4

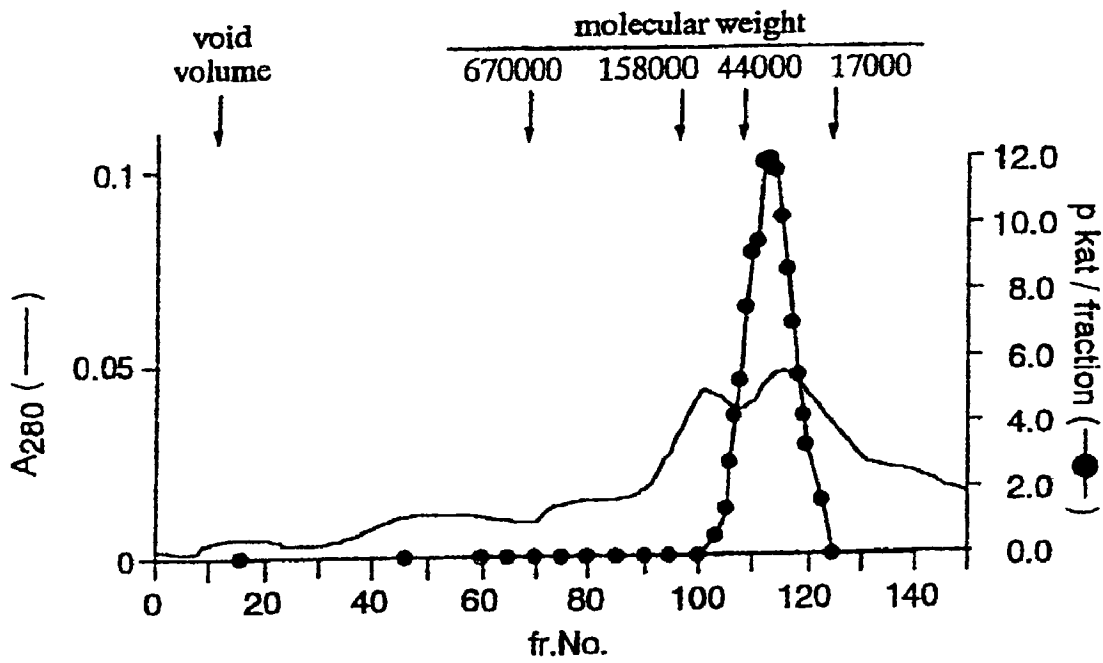


Fig. 6

GCG TTC AGA GGC TTC CAG AGT TCT TCC GST CAC CAA GAA GCA TTT GAT CAT AAC 54

19 ATG GAT GCC CAG AAC AAG GAG GTC GCT GCT CTG ATC GAG AAG ATC GCC GET ATC 108
M D A Q N K E V A A L I E K I A G I

37 CAG GCC GCC ATC GCC GAG CTG CCG TCG CTG AGC CCG TCC CCC GAG GTC GAC AGG 162
Q A A I A E L P S L S P S P E V D R

55 CTC TTC ACC GAC CTC GTC ACG GCC TGC GTC CCG CCG AGC CCC GTC GAC GTG ACG 216
L F T D L V T A C V P P S P V D V T

73 AAG CTC AGC CCG GAG CAC CAG AGG ATG CCG GAG GCT CTC ATC CGC TTG TGC TCC 270
K L S P E H Q R M R E A L I R L C S

91 GCC GCC GAG GGG AAG CTC GAG GCG CAC TAC GCC GAC CTG CTC GCC ACC TTC GAC 324
A A E G K L E A H Y A D L L A T F D

109 AAC CCG CTC GAC CAC CTC GGC CTC TTG CCG TAC TAC AGC AAC TAC GTC AAC CTC 378
N P L D H L G L F P Y Y S N Y V N L

127 AGC AGG CTG GAG TAC GAG CTC CTG GCG CCG CAC GTG CCG GGC ATC GCG CCG GCG 432
S R L E Y E L L A R H V P G I A P A

145 CCG GTC GCC TTC GTC GGC TCC GGC CCG CTG CCG TTC AGC TCG CTC GTC CTC GCC 486
R V A F V G S G P L P F S S L V L A

163 GCG CAC CAC CTG CCC GAG ACC CAG TTC GAC AAC TAC GAC CTG TGC GGC GCG GCC 540
A H H L P E T Q F D N Y D L C G A A

181 AAC GAG CCG GCC AGG AAG CTG TTC GGC GCG ACG GCG GAC GGC GTC GGC GCG CGT 594
N E R A R K L F G A T A D G V G A R

199 ATG TCG TTC CAC ACG GCG GAC GTC GCC GAC CTC ACC CAG GAG CTC GGC GCC TAC 648
M S F H T A D V A D L T Q E L G A Y

217 GAC GTG GTC TTC CTC GCC GCG CTC GTC GGC ATG GCA GCC GAG GAG AAG GCC AAG 702
D V V F L A A L V G M A A E E K A K

235 GTG ATT GCC CAC CTG GGC GCG CAC ATG GTG GAG GGG GCG TCC CTG GTC GTG CCG 756
V I A H L G A H M V E G A S L V V R

253 AGC GCA CCG CCC CCG GGC TTT CTT TAC CCC ATT GTC GAC CCG GAG GAC ATC AGG 810
S A R P R G F L Y P I V D P E D I R

271 CCG GGT GGG TTC GAG GTG CTG GCC GTG CAC CAC CCG GAA GGT GAG GTG ATC AAC 864
R G G F E V L A V H H P E G E V I N

289 TCT GTC ATC GTC GCC CGT AAG GCC GTC GAA GCG CAG CTC AGT GGG CCG CAG AAC 918
S V I V A R K A V E A Q L S G P Q N

307 GGA GAC GCG CAC GCA CCG GGC GCG GTG CCG TTG GTC AGC CCG CCA TGC AAC TTC 972
G D A H A R G A V P L V S P P C N F

325 TCC ACC AAG ATG GAG GCG AGC GCG CTT GAG AAG AGC GAG GAG CTG ACC GCC AAA 1026
S T K M E A S A L E K S E E L T A K

GAG CTG GCC TTT TGA TTG AAG AGT GCG CGT GGT CAT TCT GTC GCC TGC GAT CGT 1080
E L A F *

GGT AAC TTT CCT ACT CGT GTG TGT TTT GAT GTT TGT GCC TGT AAG AGT TAT GCT 1134
 TCC GGC CTT GTG CTG TTA ATT TAC ACG CGT TAC ATG TAG TAC TTG TAT TTA TAC 1188
 CTG GAA TAA CCG TAT GTA ACA TAA ATA TTA GTG GGA TTT GAA GTG TAA TGC TAA 1242
 ATA ATA AGA AAA CTT GAT GCA GAC ATT CAA AAA AAA AAA AAA AAA AAA AA

Fig. 7

HvNAS4 MDGQSE--EVDALVQKITGLHAAIAKLPSLSPSPDVDALFTDLVTACVPPSPVDVTKLAP
HvNAS7 MDAQSK--EVDALVQKITGLHAAIAKLPSLSPSPDVDALFTDLVTACVPPSPVDVTKLAP
HvNAS6 MDAQNK--EVDALVQKITGLHAAIAKLPSLSPSPDVDALFTDLVTACVPPSPVDVTKLGS
HvNAS2 MAAQNN-QEVDALVEKITGLHAAIAKLPSLSPSPDVDALFTELVTACVPPSPVDVTKLGP
HvNAS3 MAAQNNKDVAAALVEKITGLHAAIAKLPSLSPSPDVDALFTELVTACVPPSPVDVTKLGP
HvNAS1 MDAQNK--EVAALIEKIAGIQAAIAELPSLSPSPEVDRLFTDLVTACVPPSPVDVTKLSP
HvNAS5 MEAENG--EVAALVEKITGLHAAISKLPALSPSPQVDALFTELVAACVPPSPVDVTKLGP
* * ** ** * **

HvNAS4 EAQAMREGLIRLCSEAEGKLEAHYSOMLAAFNDPLDHLGVFPYYSNYINLSKLEYELLAR
HvNAS7 EAQAMREGLIRLCSEAEGKLEAHYSOMLAAFNDPLDHLGVFPYYSNYINLSKLEYELLAR
HvNAS6 EAQEMREGLIRLCSEAEGKLEAHYSOMLAAFNDPLDHLGMFPYYSNYINLSKLEYELLAR
HvNAS2 EAQEMREGLIRLCSEAEGKLEAHYSOMLAAFNDPLDHLGMFPYYSNYINLSKLEYELLAR
HvNAS3 EAQEMREGLIRLCSEAEGKLEAHYSOMLAAFNDPLDHLGIFPYSNYINLSKLEYELLAR
HvNAS1 EHQRNREALIRLCSAAEGKLEAHYADLLATFDNPLDHLGLFPYYSNYVNLRSLEYELLAR
HvNAS5 EAQEMRQDLIRLCSAAEGLLEAHYSOMLTALDSPLDHLGRFPYFDNYVNLSKLEHDLLAG
* * ** ** ** ** ** ** ** ** ** ** ** * * * ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **

HvNAS4 YVPGRHRPARVAFVIGSGPLPFSSYVLAARHLPDPTVFDNYDLCSAANDRATRLFRADKD-V
HvNAS7 YVPGGIAPARVAFVIGSGPLPFSSYVLAARHLPDPTVFDNYVPVRAANDRATRLFRADKD-V
HvNAS6 YVPGGIARPAVAFVIGSGPLPFSSYVLAARHLPDAMFDNYDLCSAANDRASKLFRADKD-V
HvNAS2 YVPGGYRPARVAFVIGSGPLPFSSVFLAARHLPDPTMFDNYDLCSAANDRASKLFRADRD-V
HvNAS3 YVRR-HRPARVAFVIGSGPLPFSSVFLAARHLPDPTMFDNYDLCSAANDRASKLFRADTD-V
HvNAS1 HVPG-IAPARVAFVIGSGPLPFSSVLAARHLPETQFDNYDLCSAANERARKLFGATADGV
HvNAS5 HVAA--PARVAFVIGSGPLPFSSFLATYHLPDTRFDNYDRCSVANGRAMKLVGADEGV
* * ** ** ** ** ** ** ** ** ** ** ** ** ** * * * ** ** ** * * * * * * * * * * * *

HvNAS4 GARMSFHTADVADLTDELATYDVVFLAALVGMAAEDKAKVIAHLGAHMADGAALV--ARH
HvNAS7 GARMSFHTADVADLTDELATYDVVFLAALVGMAAEDKGGQDPHLGAHMADGAALVR-SAH
HvNAS6 GARMSFHTADVADLTRELAAYDVVFLAALVGMAAEDKAKVIPHILGAHMADGAALV-RSA
HvNAS2 GARMSFHTADVADLAGELAKYDVVFLAALVGMAAEDKAKVIAHLGAHMADGAALVRSASAH
HvNAS3 GARMSFHTADVADLASELAKYDVVFLAALVGMAAEDKAKVIAHLGAHMADGAALVRSASAH
HvNAS1 GARMSFHTADVADLTQELGAYDVVFLAALVGMAAEAKAKVIAHLGAHMVEGASLVV-RSA
HvNAS5 RSRMAFHTAEVDTLTAELGAYDVVFLAALVGMTSKEKADAIAHLGKHMADGAVLVREALH
** ** ** * ** ** ** ** ** ** ** * * * ** ** ** * * * ** ** **

HvNAS4 GARGFLYPVDPQDIGRGGFEVLAVCHPD--DDVNSVIAQKSNVHEYGLGSGR--GGR
HvNAS7 GARGFLYPVDPQDIGRGGFEVLAVCHPD--DDVNSVIAQKSKDMFANGPRNGC--GGR
HvNAS6 QARGFLYPVDPQDIGRGGFEVLAVCHPD--DDVNSVIAHKSKDVHANERPNER--GGQ
HvNAS2 GARGFLYPVDPQDIGRGGFEVLAVCHPD--DDVNSVIAQKSKDVHADGLGSGRGAGGQ
HvNAS3 GARGFLYPVDPQDIGRGGFEVLAVCHPD--DDVNSVIAQKSKDVHADGLGSGRAGAGRQ
HvNAS1 RPRGFLYPVDPEDIRRGGFEVLAVHHPG--GEVINSVIVARKAVEAQLSGPQNGD---A
HvNAS5 GARAFLYPVVELDDVGRGGFQVLAVHHPAGDEVFNSFIVARKVKMSA-----
* ** ** * * ** ** ** * * * ** ** * * * * * *

HvNAS4 YARGTVVPVSPPCRFG-EMVADVTO--KREEFANAIEVAF
HvNAS7 YARG-TVPVSPPCRFG-EMVADVTO--KREEFANAIEVAF
HvNAS6 YRGA--VPVSPPCRFG-EMVADVTH--KREEFANAIEVAF
HvNAS2 YARG-TVPVSPPCRFG-EMVADVTONHKRDEFANAIEVAF
HvNAS3 YARG-TVPVSPPCRFG-EMVADVTONHKRDEFANAIEVAF
HvNAS1 HARG-AVPLVSPPCNFSTKMEASALE--KSEELTAKELAF
** ** ** * * * * * * * * * * * *

Fig. 8

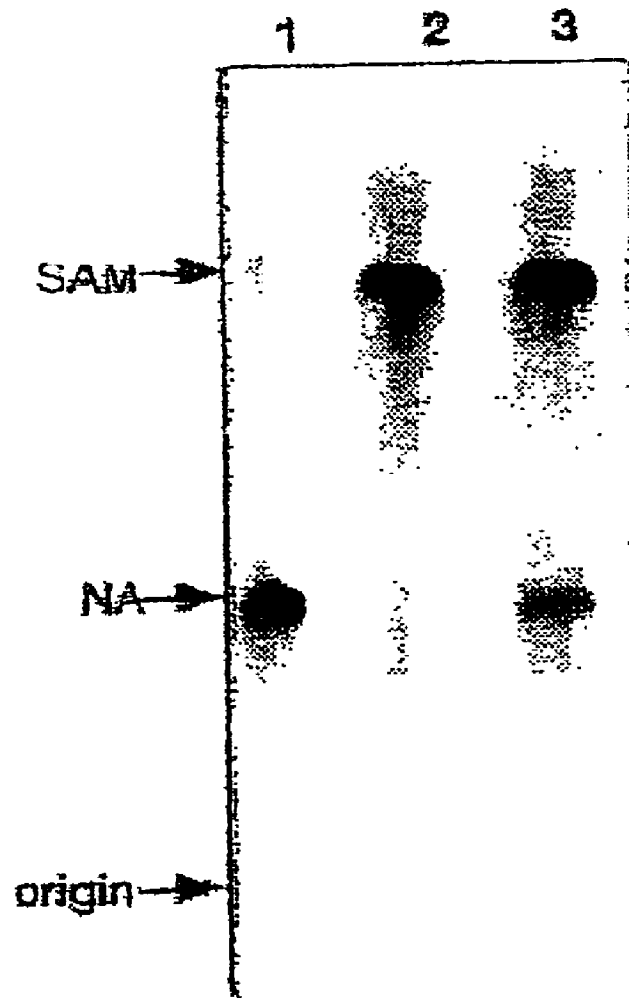


Fig. 9

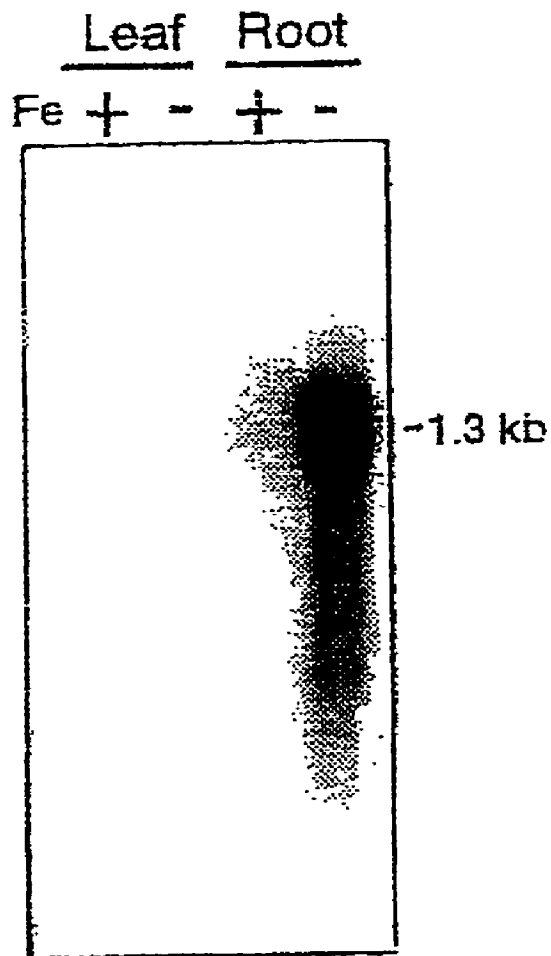


Fig. 10

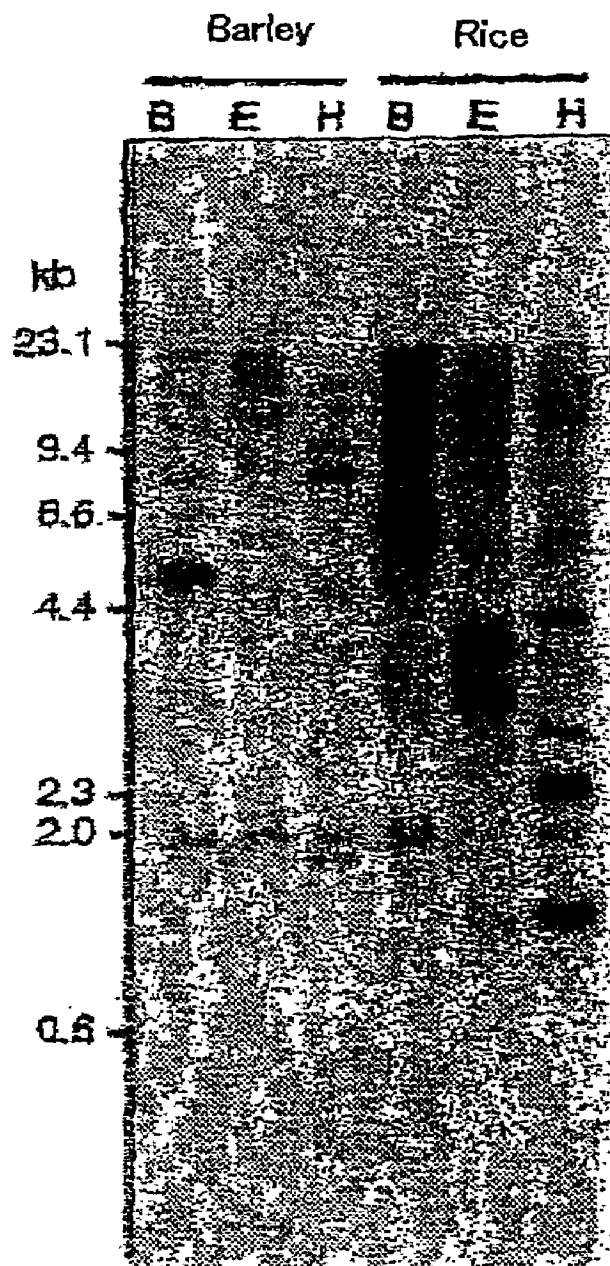


Fig. 11

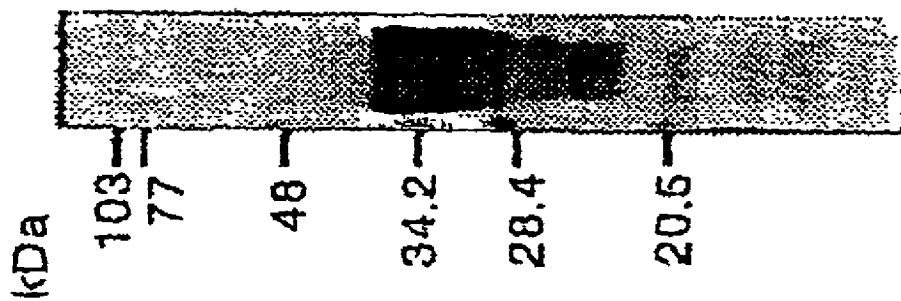


Fig. 12

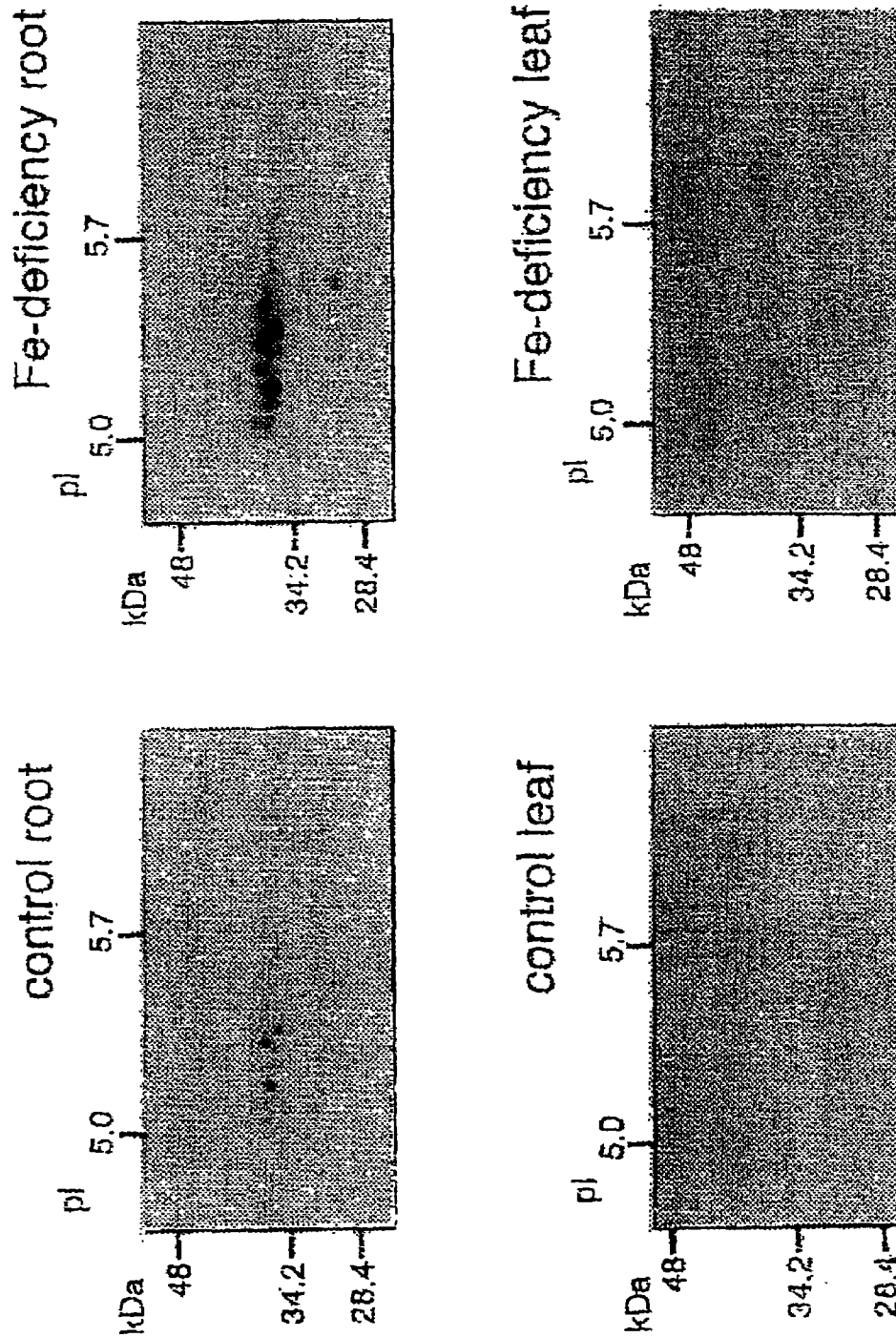


Fig. 13

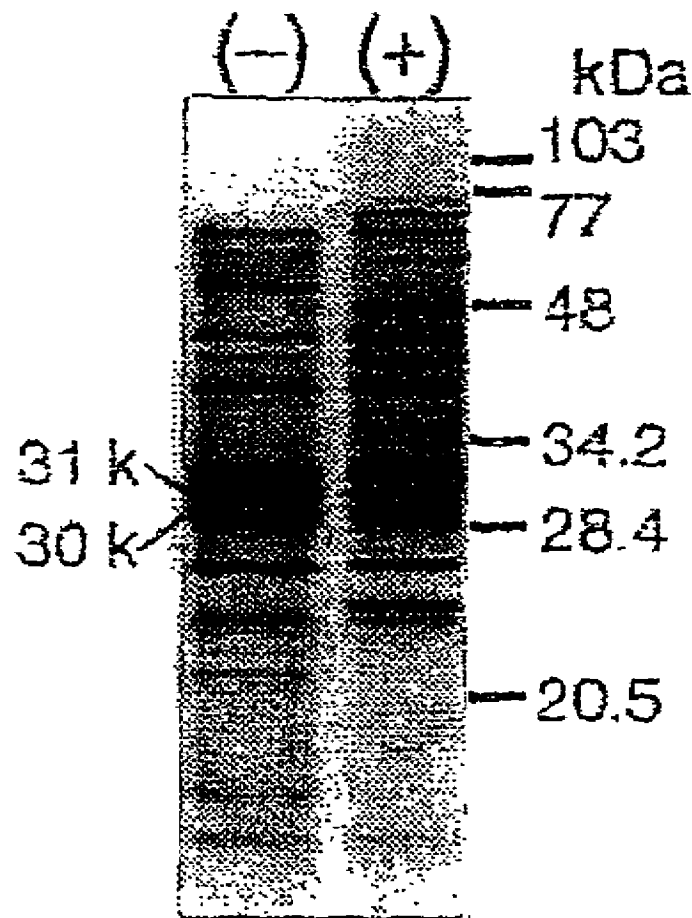


Fig. 14

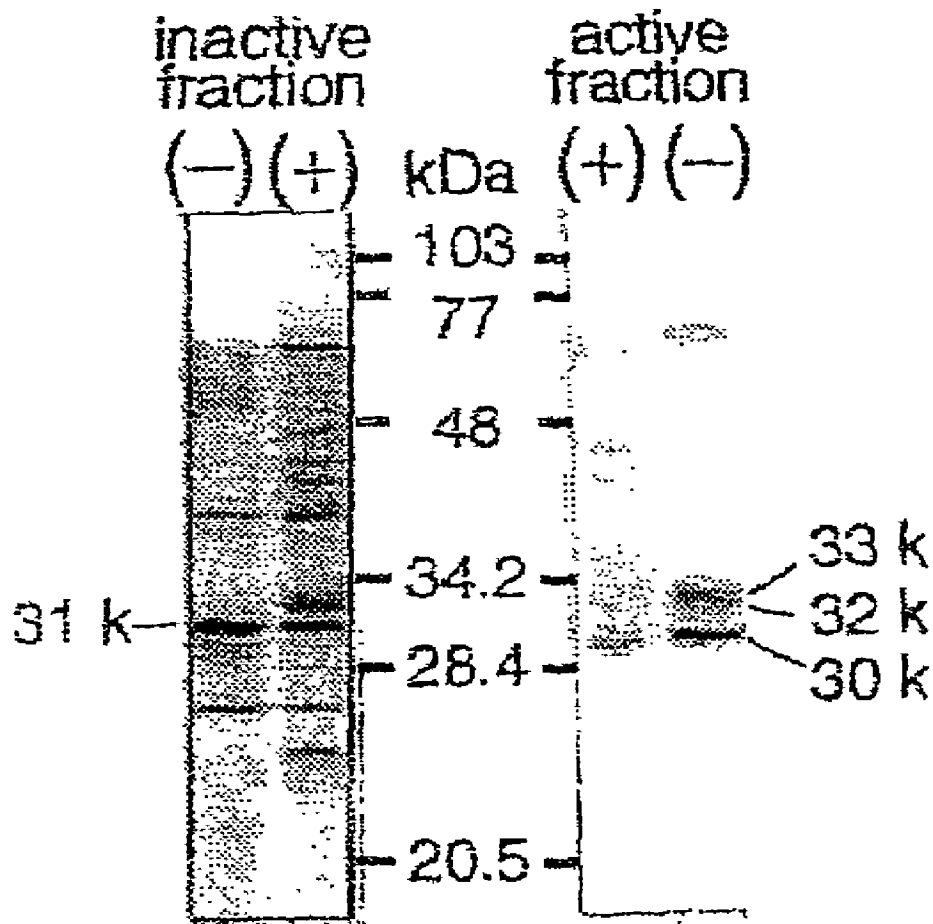


Fig. 15

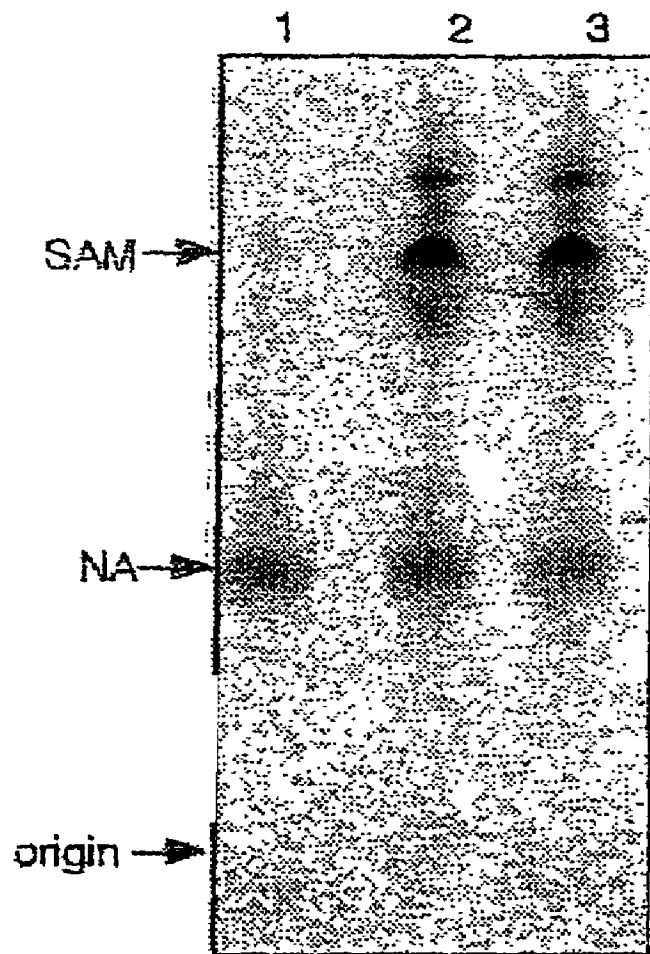


Fig. 16

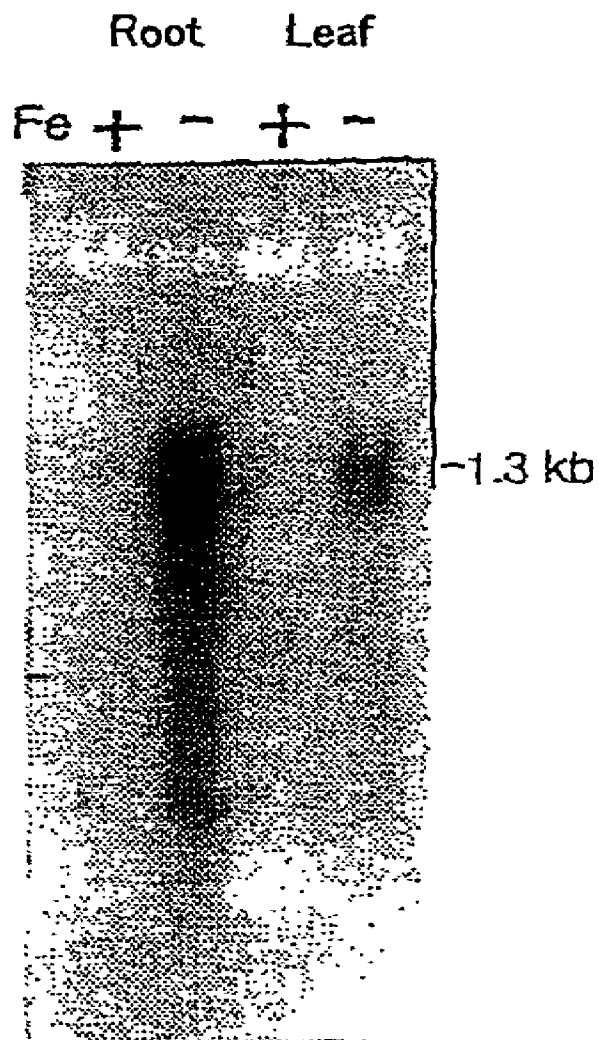


Fig. 17

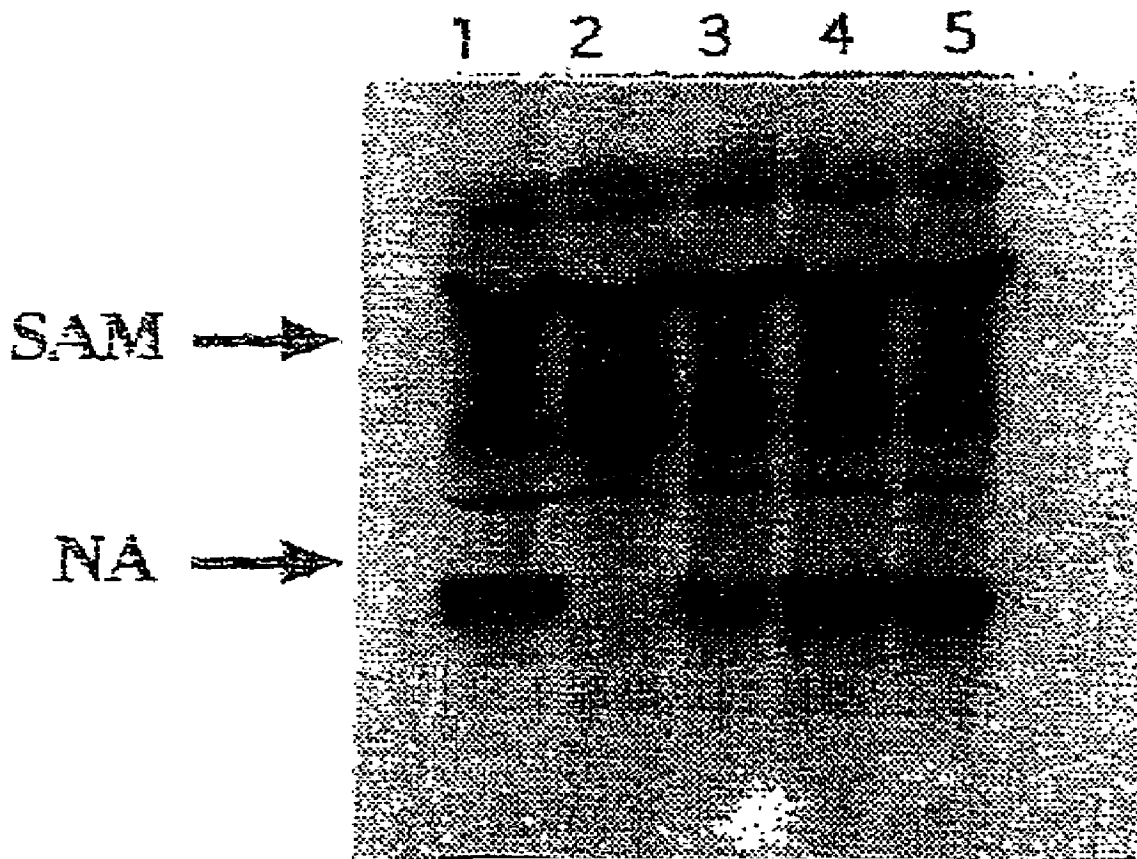
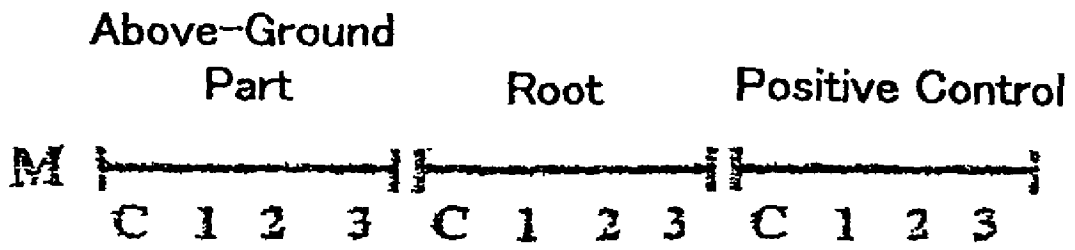


Fig. 18



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NICOTIANAMINE SYNTHASE AND GENE ENCODING THE SAME

This is a divisional application which claims the benefit of U.S. patent application Ser. No. 09/674,337, filed on Jul. 26, 2001, which is incorporated by reference.

TECHNICAL FIELD

The present invention relates to a nicotianamine synthase involved in the mugineic acid biosynthetic pathway, the amino acid sequence thereof, a gene encoding the same, a vector, a process for producing nicotianamine by using the same, plants transformed by the gene encoding the nicotianamine synthase, and an antibody against the nicotianamine synthase.

BACKGROUND ART

Graminaceous plants that absorb by chelating the insoluble state Fe(III) in soil using mugineic acid and adopt so called the Strategy-II mechanism of Fe acquisition secrete Fe chelators (phytosiderophores) from their roots to solubilize sparingly soluble Fe in the rhizosphere (Roemheld, 1987). The amount of the secreted phytosiderophores increases under Fe-deficiency stress. The mugineic acid family is the only examples of phytosiderophores known so far (Takagi, 1976). Tolerance to Fe deficiency in graminaceous plants is thought to depend on a quantity of mugineic acid family secreted by plants (Takagi et al. 1984, Roemheld and Marschner 1986, Marschner et al. 1987, Mori et al. 1987, Kawai et al. 1988, Mori et al. 1988, Mihashi and Mori 1989, and Shingh et al. 1993).

The biosynthetic pathway of mugineic acid in plants is shown in FIG. 1. S-adenosylmethionine is synthesized from methionine by S-adenosylmethionine synthase. Subsequently, three molecules of S-adenosylmethionine are combined to form one molecule of nicotianamine by nicotianamine synthase. The generated nicotianamine is then converted to 3"-keto acid by nicotianamine aminotransferase, and 2'-deoxymugineic acid is synthesized by the subsequent action of a reductase. A further series of hydroxylation steps produces the other mugineic acid derivatives including mugineic acid from the deoxymugineic acid (Mori and Nishizawa 1987, Shojima et al. 1989, Shojima et al. 1990 and Ma and Nomoto 1993).

A compound in FIG. 1, a compound in the lower right, wherein R₁ and R₂ are hydrogen and R₃ is hydroxyl, is mugineic acid. A compound wherein R₁ is hydrogen and R₂ and R₃ are hydroxyl, is 3-hydroxymugineic acid. Also a compound wherein R₂ is hydrogen and R₁ and R₂ are hydroxyl, is 3-epihydroxymugineic acid.

Three S-adenosylmethionine synthase genes were isolated from barley roots, but these genes were not induced by Fe deficiency (Takizawa et al. 1996). A gene lds3, which is obtained from the barley by differential screening, is suspected to be a gene, which converts deoxymugineic acid to mugineic acid by hydroxylation and is strongly induced by Fe-deficiency (Nakanishi et al. 1993). Further, nicotianamine aminotransferase was purified and isolated from Fe-deficient barley roots, and two nicotianamine aminotransferase genes, Naat-A and Naat-B, were isolated (Takahashi et al. 1997). Naat-A expression was induced in Fe-deficient roots.

The synthesis of nicotianamine from S-adenosylmethionine is similar to polyamine synthesis from decarboxy-S-adenosylmethionine. In contrast to polyamine synthase,

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however, nicotianamine synthase catalyzes the combination of three S-adenosylmethionine molecules and the azetidine ring formation at the same time (FIG. 1). Such the nicotianamine synthase is a novel type of enzyme. Previously, we reported the partial purification of nicotianamine synthase from the roots of Fe-deficient barley and expression pattern of the activity (Higuchi et al. 1994, Higuchi et al. 1995, Kanazawa et al. 1995, Higuchi et al. 1996a and Higuchi et al. 1996b). Since nicotianamine synthase is easily decomposed during extraction and purification, it has been difficult to purify sufficient quantities for amino acid sequencing.

The present invention has an object to provide a plant, especially graminaceous plant, highly tolerant to Fe-deficiency, as a result of isolating and purifying a nicotianamine synthase, being cloned the gene of this enzyme, determining the base sequence and amino acid sequence thereof, and using said enzyme.

DISCLOSURE OF INVENTION

The present invention relates to a nicotianamine synthase shown in SEQ ID NO: 1 comprising amino acid sequence shown in SEQ ID NO: 1, or amino acid sequence having deletion in a part thereof, being substituted by the other amino acids or being added with the other amino acids.

The present invention relates to the gene encoding said amino acid sequence of nicotianamine synthase.

The present invention also relates to a vector comprising containing said gene, and a transformant transformed by the said vector.

The present invention relates to a process for production of nicotianamine using the said transformant.

The present invention further relates to plants, especially graminaceous plants, to which said gene is introduced, and fruits obtained by growing said plants.

The present invention relates to a process for extraction of said nicotianamine synthase in the presence of thiol protease inhibitor, preferably E-64.

Further, the present invention relates to an antibody against said nicotianamine synthase.

BRIEF DESCRIPTION OF DRAWING

FIG. 1 shows the biosynthetic pathway of mugineic acid family.

FIG. 2 shows a comparison of nicotianamine synthase purification from Fe-dependent and control barley roots.

FIG. 3 shows a preparative SDS-PAGE (sodium dodecyl sulfate-polyacrylamide gel electrophoresis, hereinafter designates as SDS-PAGE) around 30-35 kDa. The horizontal bar indicates relative enzyme activity detected from the gels.

FIG. 4 shows elution pattern of nicotianamine synthase activity from the gel-filtration column.

The large closed circles (●) indicates enzyme activity.

FIG. 5 shows a comparison with a six partial amino acid sequence determined by nicotianamine synthase originated from barley and similar sequence of graminaceous plants obtained by computer search of the database. Identical amino acid residue is shown in ":"(SEQ ID NOS 30-37, respectively in order of appearance).

FIG. 6 shows full length of HvNAS1 cDNA (SEQ ID NO:2) and amino acid sequence (SEQ ID NO:1) deduced therefrom. The underlined sequences indicate the identical partial amino acid sequences of fragments in the above FIG. 5. Numbers of the nucleotide sequence are indicated to the right of each row. Amino acid numbers are indicated on the left of each row.

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FIG. 7 shows comparison of the deduced amino acid sequences of the above 7 cDNA obtained from barley (SEQ ID NOS 7, 13, 11, 3, 5, 1, and 9, respectively in order of appearance). Asterisks "*" indicates identical amino acid residues in all sequences used to generate consensus sequences SEQ ID NOS: 23–29.

FIG. 8 shows results of thin layer chromatographic (TLC) analysis of nicotianamine synthase activity obtained from *E. coli* crude extract expressing a fused protein of maltose binding protein—HvNAS1.

FIG. 9 shows Northern—hybridization analysis of HvNAS1 as a probe.

FIG. 10 shows Southern—hybridization analysis of HvNAS1 as a probe.

FIG. 11 shows Western-blot analysis of crude enzyme used for detection of nicotianamine synthase activity.

FIG. 12 shows Western-blot analysis of total protein extracted by trichloroacetic acid/acetone.

FIG. 13 shows comparison of nicotianamine synthase purification from Fe-deficient barley and control barley after DEAE-Sepharose FF.

FIG. 14 shows comparison of nicotianamine synthase purification from Fe-deficient barley and control barley after Ether Toyopearl 650M.

FIG. 15 shows results of thin layer chromatographic (TLC) analysis of nicotianamine synthase activity obtained from *E. coli* crude extract expressing a fused protein of maltose binding protein—OsNAS1.

FIG. 16 shows Northern—hybridization analysis of OsNAS1 as a probe.

FIG. 17 shows results of thin layer chromatographic (TLC) analysis of nicotianamine synthase activity obtained from *E. coli* crude extract expressing a fused proteins of maltose binding protein—AtNAS1, AtNAS2 or AtNAS3.

FIG. 18 shows results of RT-PCR of total RNA extracted from the aboveground parts and roots of *Arabidopsis thaliana*. Right group indicates positive control.

BEST MODE FOR CARRYING OUT THE INVENTION

We have tried to isolate nicotianamine synthase (Higuchi et al. *Plant & Soil*, Vol. 165, p. 173–179, 1994), and since nicotianamine synthase was easily decomposed and was difficult to isolate and purify, we were unable to obtain sufficient amounts of protein to determine its partial amino acid sequence. Subsequently, it was found that a thiol protease inhibitor E-64 (hereinafter designates as E-64) was very effective in suppressing degradation of nicotianamine synthase (Higuchi et al. *Plant & Soil*, Vol. 178, p. 171–177, 1996 a).

In the present invention, as a result that frozen roots were crushed to a fine powder in liquid N₂ and then rapidly homogenized with buffer containing 0.1 mM thiol protease inhibitor E-64, nicotianamine synthase protein could be isolated and its gene could also be isolated.

Further, the enzyme of the present invention recovered its activity by removal of SDS after SDS-PAGE treatment, but the rate of recovery was very low (Higuchi et al. *Plant & Soil*, Vol. 165, p. 173–179, 1994). Consequently, degree of purification should be increased up before treatment of SDS-PAGE. Then the column chromatography procedures were further improved.

We have also found that the enzyme of the present invention is relatively hydrophobic and a buffer containing a mild surface active agent CHAPS increased the rate of recovery. Several ion-exchange chromatography carriers

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were tested, and DEAE-Sepharose FF and DEAE Sephacel were found to be the most effective. In addition to TSK gel Butyl Toyopearl, another hydrophobic chromatography carrier, TSK gel Ether Toyopearl 650M, effectively removed impurities of the 30–35 kDa.

The enzyme of the present invention has been reported that it was the peptide of 30–35 kDa, the activity of which was recovered by removing SDS after SDS-PAGE treatment, and the activity was detected as a broad molecular weight range of 30–35 kDa (refer to FIG. 3). FIG. 3 shows a result of preparative SDS-PAGE in the fractions showing enzyme activity. SDS-PAGE was carried out using 11% acrylamide slab gels. A portion of the gel was stained with Coomassie brilliant blue and the rest of the gel was stained with Cu. The gel containing proteins between 30–35 kDa in size was cut into seven fragments (indicated by the short lines). The thick bars in FIG. 3 indicate relative enzymatic activities detected from each gel fragment.

In order to identify nicotianamine synthase peptide from the proteins having these molecular weights, the peptides, which were contained in the nicotianamine synthase fractions, purified from Fe-deficient and control barley roots were compared using SDS-PAGE. From each barley root 200 g, the present enzyme was purified according to the method described in example 3 hereinbelow.

The enzyme activity of the control was a quarter of the Fe-deficient roots.

The peptide composition of the active enzyme fraction from each purification step of the present enzyme was analyzed and compared by SDS-PAGE, and results are shown in FIG. 2, FIG. 13 and FIG. 14. FIG. 2, FIG. 13 and FIG. 14 show comparison with the active fraction from the purification step of Fe-deficient barley roots 200 g [in the figure, shown with (-)], and the active fraction from the purification step of the control barley roots 200 g [in the figure, shown with (+)]SDS-PAGE was carried out using 12.5% acrylamide slab gels (Laemmli, *Nature* Vol. 227, p. 680–685, 1970). Gels were stained with Coomassie brilliant blue. FIG. 2 shows a step before DEAE-Sepharose. The upper row shows enzyme from Fe-deficient barley roots and the lower row shows enzyme from control roots. In each lane, lanes 1, crude extract, 200 µg of protein; lanes 2, after Butyl Toyopearl 650M, 100 µg of protein; lanes 3, after Hydroxyapatite, 20 µg of protein; and lanes 4, after Butyl Toyopearl 650M, 15 µg of protein, are shown.

FIG. 13 shows after DEAE-Sepharose FF, each lane, 25 µg of protein. FIG. 14 shows after Ether Toyopearl 650M; in which left shows inactive fraction, and right shows active fraction, and 1/2s of each fraction is electrophoresed.

As a result, almost no difference was observed in both Fe-deficient and control roots before DEAE-Sepharose step (refer to FIG. 2). After the DEAE-Sepharose step it became clear that the 30- and 31-kDa peptides were induced by Fe-deficiency (refer to FIG. 13). After the Ether Toyopearl step, the 31 kDa peptide was eliminated from the active fraction. The 32 and 33 kDa peptides were found to be newly induced by Fe-deficiency (refer to FIG. 14). Activities were detected from the 32 and 33 kDa peptides, but no activity was detected from 30 kDa peptide (refer to FIG. 3).

Molecular weight of the enzyme of the present invention was determined by gel-filtration.

Estimated molecular weight of nicotianamine synthase by gel-filtration was reported to be 40,000–50,000 (Higuchi et al. *Plant & Soil*, Vol. 165, p. 173–179, 1994). But this did not correspond with the value estimated by SDS-PAGE.

In the present study, the buffer containing CHAPS effectively increased the resolution and molecular weight of the

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present enzyme was estimated to be 35,000 (refer to FIG. 4). This corresponds well to the value estimated by SDS-PAGE.

FIG. 4 shows elution pattern of nicotianamine synthase from the gel-filtration column. The black circles (●) indicate the enzyme activity and the solid line indicates absorption at 280 nm. The active fraction after hydroxyapatite chromatography was applied to a Sephacryl S300HR (Pharmacia) column (1.5 cm×71 cm, 125 ml), equilibrated with developing buffer (50 mM Tris, 1 mM EDTA, 0.1 M KCl, 0.05% CHAPS, 0.1 mM p-APMSF and 3 mM DTT, pH 8.0). Molecular weight markers used were thyroglobulin (Mr 670,000), γ -globulin (Mr 158,000), ovalbumin (Mr 44,000), and myoglobin (Mr 17,000). The linear flow was 10 cm/hour.

Partial amino acid sequence was determined from purified nicotianamine synthase.

The above explained 30 kDa, 32 kDa and 33 kDa peptides were purified from 1 kg of Fe-deficient barley roots by using a method in example 3 hereinbelow. These were partially degraded using a method in example 4 hereinbelow. Although 32- and 33-kDa peptides could not be completely separated from each other, these might have similar sequence or 32 kDa peptide was presumed to be the degradation product of 33 kDa peptide, and both of them were degraded in together.

The determined partial amino acid sequences indicated that these peptides were very similar in each other (FIG. 5). Further, since the molecular weights of the 33 kDa and 32 kDa (1) fragments had almost unchanged molecular weight as compared with before degradation, this sequence might be N-terminal region of the present enzyme. As a result of computer search of the database, a gene of unknown function having very similar sequence to these sequences was found to exist in *Oryza sativa* and *Albidopsis thaliana*. Especially, EST-cDNA clones D23792 and D24790 of *Oryza sativa* were very similar with 80.0% identity in a 33-amino acid overlap in the former and 68.4% identity in a 19-amino acid overlap in the latter (FIG. 5).

FIG. 5 shows a comparison with a six partial amino acid sequence determined by nicotianamine synthase originated from barley and similar sequence of graminaceous plants obtained by computer search of the database. Identical amino acid residue is shown in “:”. The part of nucleotide sequences indicated by the arrows was applied for the sequences of primer used in PCR.

Cloning and nucleotide sequences of cDNA clones encoding nicotianamine synthase were performed and determined.

PCR amplification of total cDNA prepared from Fe-deficient barley roots using degenerate primers designed from the partial amino acid sequence obtained from the method explained hereinbefore was performed, but the objective DNA could not be amplified. Then the primers having single nucleotide sequence (shown by arrows in FIG. 5) from sequences of *Oryza sativa*, D23792 and D24790, were synthesized and PCR amplification was performed. The 205 bp fragment was amplified by PCR using NF and NR primers and the 274 bp fragment was amplified by PCR using IF and IR primers, and these contained the objective sequences. A cDNA library prepared using poly (A)⁺RNA from Fe-deficient barley roots was screened and 19 positive clones using the 205 bp fragment probe and 88 positive clones using the 274 fragment bp probe were obtained.

Among the thus obtained clones, the clone designated as HvNAS1, contained a translated region of 985 bp and amino acid sequence deduced therefrom was 328 amino acids residue, with deduced molecular weight of 35,144. This corresponded well with the value estimated by SDS-PAGE

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and gel-filtration. The partial amino acid sequences of the 32 kDa and 33 kDa peptides were included totally in HvNAS1 (FIG. 6).

FIG. 6 shows full length of HvNAS1 cDNA and amino acid sequence deduced therefrom. The underlined sequences indicate the identical partial amino acid sequences of fragments in the above FIG. 5. Numbers of the nucleotide sequence are indicated to the right of each row. Amino acid numbers are indicated on the left of each row.

The predicted pI of 5.2 matched the value estimated by native isoelectric focusing electrophoresis well. The six clones having very similar sequence other than HvNAS1, i.e. HvNAS2, HvNAS3, HvNAS4, HvNAS5, HvNAS6 and HvNAS7, were also obtained (Table 1, FIG. 7).

FIG. 7 shows comparison of the deduced amino acid sequences of the above 7 cDNA obtained from barley. Asterisks “*” indicates identical amino acid residues in all sequences.

The nucleotide sequences of these clones are shown in SEQ ID NO: 2 (HvNAS1), SEQ ID NO: 4 (HvNAS2), SEQ ID NO: 6 (HvNAS3), SEQ ID NO: 8 (HvNAS4), SEQ ID NO: 10 (HvNAS5), SEQ ID NO: 12 (HvNAS6) and SEQ ID NO: 14 (HvNAS7), respectively. The amino acid sequences of these amino acid sequences are shown in SEQ ID NO: 1 (HvNAS1), SEQ ID NO: 3 (HvNAS2), SEQ ID NO: 5 (HvNAS3), SEQ ID NO: 7 (HvNAS4), SEQ ID NO: 9 (HvNAS5), SEQ ID NO: 11 (HvNAS6) and SEQ ID NO: 13 (HvNAS7), respectively.

TABLE 1

Properties of nas clones						
Clone	Number of Amino Acid Residues	Molecular Weight	pI	Identity to nas 1 (%)	Identity to nas 2 (%)	Identity to nas 4 (%)
HvNAS 1	328	35144	5.20	—	—	—
HvNAS 2	336	35839	5.07	72	—	—
HvNAS 3	336	36013	5.47	72	95	—
HvNAS 4	330	35396	4.91	73	89	—
HvNAS 5	283	30148	5.22	61	61	59
HvNAS 6	329	35350	5.07	74	89	88
HvNAS 7	330	35244	4.98	70	86	91

The partial amino acid sequences determined from the 30 kDa peptide were all included in HvNAS5. The 5'- and 3'-non-translated regions of these clones were not similar with each other.

D23792 and D24790 similar to nicotianamine synthase of *Oryza sativa* were found with about 80% identity to HvNAS1. AC003114 and AB005245 of *Arbidopsis thaliana* were found with about 45% identity to HvNAS1.

The obtained HvNAS 1 protein was expressed in *E. Coli*.

The PCR amplification of HvNAS1 ORF was cloned with vector pMAL-c2 to express HvNAS1 fused with C-terminal of maltose binding protein. The expression of fused protein is strongly induced by IPTG.

The crude extract was obtained from the transformed *E. coli*, and nicotianamine synthase activity was assayed in the state of the fused protein. The crude extract from the strain transformed with only the vector could not be detected the activity, whereas in case of inserted with HvNAS1 ORF, the activity was detected. Result is shown in FIG. 8.

FIG. 8 shows results of thin layer chromatographic (TLC) analysis of nicotianamine synthase obtained from *E. coli* crude extract expressing a fused protein of maltose binding protein—HvNAS1. In FIG. 8, lane 1: a standard nicotianamine synthase; lane 2: *E. coli* expressing maltose binding

protein (SAM); and lane 3: *E. coli* expressing maltose binding protein—HvNAS 1 fused protein.

Northern hybridization analysis conducted by the method described in example 7 hereinbelow indicated that this gene was strongly induced in Fe-deficient roots (FIG. 9). This coincides with expression pattern of the present enzyme activity (Higuchi et al. 1994). FIG. 9 shows a result of Northern hybridization analysis using HvNAS1 as a probe. Total RNA was extracted from after one week of Fe-deficient treatment and control barley leaves and roots, and in each lane, 5 µg of RNA were electrophoresed.

Southern hybridization analysis of the barley genome DNA was performed according to the method described in example 8 hereinafter mentioned. Cutting of DNA with BamHI, EcoRI or HindIII produced plurality of fragments, however none of the clones obtained at present could be digested by BamHI and EcoRI, consequently nicotianamine synthase gene might exist with multiple copies in genomes of barley and rice (FIG. 10).

FIG. 10 shows Southern—hybridization analysis of HvNAS1 as a probe. Genomic DNAs from barley and rice were digested with BamHI (lanes B), EcoRI (lanes R) and HindIII (lanes H) and 10 µg thereof were electrophoresed in each lane.

Further, using antigen prepared by the method described in example 9 hereinbelow, Western-blot analysis was performed according to the method described in example 10. It was found that the present enzyme protein was rapidly decomposed during the operation in the crude extract prepared for detecting the present enzyme activity (FIG. 11). The staining patterns coincided with the fact that the present enzyme activity was detected on the broad range between 30–35 kDa after SDS-PAGE (refer to FIG. 3).

FIG. 11 shows Western-blot analysis of crude enzyme used for detection of activity. SDS-PAGE was performed using 12.5% acrylamide slab gel. Protein 100 µg was electrophoresed.

The crude extract obtained from denatured protein according to the method described in example 10 hereinbelow was detected as almost single band with 35–36 kDa (FIG. 12). This value coincided with the deduced value from the amino acid sequence.

FIG. 12 shows Western-blot analysis of total protein extracted by trichloroacetic acid/acetone. SDS-PAGE was performed using 12.5% acrylamide slab gel. Protein 100 µg was electrophoresed. Proteins 200 µg extracted from roots and proteins 500 µg extracted from leaves were electrophoresed.

Western-blot analysis after 2-dimension electrophoresis reveals to detect several spots. This coincided with the fact of obtaining plurality of nicotianamine synthase gene. All spots were induced in Fe-deficient roots.

As a result that cDNA library from Fe-deficient rice roots poly (A)+RNA was screened using probes prepared by cutting HvNAS1 with restriction enzymes ApaI and XhoI, 20 clones were obtained. These clones were divided into 3 types of clones according to their sequences, and among them, only one type contains ORF full length, which was designated as OsNAS1. Nucleotide sequence of OsNAS1 is shown in SEQ ID NO: 16 and amino acid sequence is shown in SEQ ID NO: 15.

PCR amplification of OsNAS1 ORF was cloned with a vector pMAL-c2 to express a form fused with maltose binding protein C-terminal. The fused protein is strongly induced its expression by IPTG.

Crude extract from the transformed *E. coli* with the fused protein was obtained and nicotianamine synthase activity

was assayed in the state of the fused protein. The same activity with HvNAS1 was detected. Result is shown in FIG. 15. FIG. 15 shows results of thin layer chromatographic (TLC) analysis of nicotianamine synthase obtained from *E. coli* crude extract expressing a fused protein of maltose binding protein—OsNAS1. In FIG. 15, lane 1: a standard nicotianamine (NA); lane 2: an extract from *E. coli* expressing maltose binding protein—OsNAS1 fused protein; and lane 3: an extract from *E. coli* expressing maltose binding protein—HvNAS1 fused protein.

Northern hybridization analysis conducted by the method described in example 7 hereinbelow indicated that in contrast to barley, the expression was induced in rice by Fe-deficient treatment not only in roots but also in leaves (FIG. 16). FIG. 16 shows a result of Northern hybridization analysis using OsNAS1 ORF as a probe. Total RNA was extracted from after two weeks of Fe-deficient treatment and control rice leaves and roots, and in each lane, 5 µg of RNA were electrophoresed.

Nucleotide sequence of *Arabidopsis thaliana* similar to HvNAS1 obtained by computer search of the database was used as a primer. PCR amplification for genome DNA of *Arabidopsis thaliana* resulted to obtain three nicotianamine synthase genes. These were designated as AtNAS1, AtNAS2 and AtNAS3.

Nucleotide sequence of these genes are shown in SEQ ID NO: 18 (AtNAS1), SEQ ID NO: 20 (AtNAS2) and SEQ ID NO: 22 (AtNAS3). These amino acid sequences are shown in SEQ ID NO: 17 (AtNAS1), SEQ ID NO: 19 (AtNAS2) and SEQ ID NO: 21 (AtNAS3).

AtNAS1, AtNAS2 and AtNAS3 ORF were amplified with PCR and were cloned with a vector pMAL-c2. Each of them was tried to be expressed in the form of fusing with maltose binding protein C-terminal. The expression of the fused protein was strongly induced by IPTG.

Crude extract from the transformed *E. coli* with the fused protein was obtained and nicotianamine synthase activity was assayed in the state of the fused protein. The activity was detected. Result is shown in FIG. 17. FIG. 17 shows results of TLC analysis of nicotianamine synthase activity obtained from *E. coli* crude extract expressing a fused protein of maltose binding protein—AtNAS. In FIG. 17, lanes 1: a standard nicotianamine (NA) and S-adenosylmethionine; lanes 2: an extract from *E. coli* expressing only maltose binding protein; lanes 3: an extract from *E. coli* expressing maltose binding protein—AtNAS1 fused protein; lanes 4: an extract from *E. coli* expressing maltose binding protein—AtNAS2 fused protein; and lanes 5: an extract from *E. coli* expressing maltose binding protein—AtNAS3 fused protein.

RT-PCR was conducted according to the method described in example 11 hereinbelow. It was found that AtNAS1 was expressed in the roots and the aboveground parts of *Arabidopsis thaliana*, whereas AtNAS2 was expressed neither in the roots nor in the aboveground parts, and AtNAS3 was expressed only in the roots (FIG. 18). In FIG. 18, lane M shows molecular weight marker. Gene expression was conducted in the aboveground parts, roots and positive controls. In the figure, lanes C: AtNAS1 and AtNAS2 ORF full length were amplified; lanes 1: AtNAS1 specific amplification fragments; lanes 2: AtNAS2 specific amplification fragments; and lanes 3: AtNAS3 specific amplification fragments.

The amount of secreted mugineic acid is reported increased up to 20 mg mugineic acid/g roots dry weight/day (Takagi, 1993). Crude nicotianamine synthase activity detected by the present inventors was sufficient to fulfill it.

Since the present enzyme proteins exist in more than several types and 30 kDa peptide without activity exists, it can be speculated that as a result of aggregation of these peptides, the constructed structure, which is preferable for binding with 3 molecules of S-adenosylmethionine, reveals maximum activity. The molecular weight estimated by gel-filtration was 35,000 (FIG. 4).

Increase in activity by re-aggregation of subunits has not been observed at present. Since the fused protein with maltose binding protein and subunits showed its activity, we have at present an idea that the present enzyme might be a monomer. However, the possibility that large activity can be revealed by constructing multimer, can not completely be denied.

The reaction mechanism synthesizing nicotianamine from S-adenosylmethionine may be similar to methyl transfer reaction using S-adenosylmethionine as a methyl donor, and a reaction synthesizing spermidine and spermine from decarboxylated S-adenosylmethionine. The common catalytic domain of these enzymes has been discussed in relation to equivalent amino acids configuration occupying similar positions in higher-order structures (Hashimoto et al. 1998 and Schluckebier et al. 1995).

In future, catalytic domain may be elucidated as the results of comparison with nicotianamine synthase from other plant species or X-ray crystallography.

Induction of nicotianamine synthase activity by Fe-deficiency, is a specific phenomenon in graminaceous plants, and is essential for mass production of mugineic acid family. *Oryza sativa* is a plant, in which secretion of mugineic acid family is the least among major graminaceous plants, consequently it is very weak for Fe-deficiency in calcareous soil.

Consequently, as a result of creating transformant *Oryza sativa* having tolerance to Fe-deficiency by introducing nicotianamine synthase gene of the present invention into the graminaceous plants, especially *Oryza sativa*, and expressing large amount at the Fe-deficiency, cultivation of rice in the calcareous soil can be possible.

Heretofore, in the graminaceous plants, nicotianamine has been thought to have only a role as a precursor for synthesis of mugineic acid family. However, since the present invention has elucidated that nicotianamine synthase gene constituted the multiple gene family, it may play other important roles in the graminaceous plants.

In plants, which lack the ability to secrete mugineic acid family, except for graminaceous plants, it has been proposed that nicotianamine plays a key role as an endogenous chelator of divalent metal cations, such as Fe^{2+} , Cu^{2+} , Zn^{2+} and Mn^{2+} , and that it contributes to the homeostasis of those metals (Stephan et al. 1994). Consequently, it may play the same role in the graminaceous plants.

Nicotianamine synthase activity is not induced in dicots, and expression of gene of the present invention may not be induced by Fe-deficiency. We have cloned nicotianamine synthase genes of *Arabidopsis thaliana*. Composition of promoter regions in these genes can elucidate the mechanism of gene expression caused by Fe-deficiency, and the gene of the present invention may play important function not only in the graminaceous plants but also in the dicots.

SEQ ID NO: 1 shows amino acid sequence of nicotianamine synthase of the present invention.

The present invention includes nicotianamine synthase having amino acid sequence shown in SEQ ID NO: 1. However, the present invention is not limited within the above nicotianamine synthase. The nicotianamine synthase of the present invention includes, unless it loses nicotian-

amine synthase activity, the peptides, in which a part of the amino acid sequence of said peptide is deleted, preferably 50% or less, more preferably 30% or less, or more further preferably 10% or less in the total amino acids, or is substituted by other amino acids, or to which other amino acids are further added, or in which these deletion, substitution and addition may be combined.

Nucleotide sequence coding nicotianamine synthase of the present invention is shown in SEQ ID NO: 2.

The present invention also includes not only a gene coding nicotianamine synthase shown in SEQ ID NO: 2 but also genes coding nicotianamine synthase mentioned hereinabove.

The vector of the present invention introducing the above gene is not specifically limited, and various vectors can be introduced. Preferable vector is the expression vector.

Various cells can be transformed conventionally by using recombinant vector of the present invention. Mass production of nicotianamide can be performed by using the thus obtained transformant. These methods are well known in the person skilled in the art.

Examples of hosts for introducing the gene of the present invention are bacteria, yeasts and cells. Preferable host is plants, especially the graminaceous plant.

Method for introducing gene is not limited. It can be made by using vector or can be directly introduce in genome.

Antibody of the present invention against nicotianamine synthase can be prepared conventionally by using nicotianamine synthase of the present invention. Antibody can be a polyclonal antibody or, if necessary, monoclonal antibody.

Further, a selective breeding of plants, preferably graminaceous plants, can be made by using gene of the present invention. Especially, the gene of the present invention can be applied for improvement of varieties, which can grow even in Fe-deficient soil.

EXAMPLES

The following examples illustrate the present invention, but are not construed as limiting the present invention.

Example 1

Preparation of Plant Material

Seeds of barley (*Hordeum vulgare* L. cv Ehimehadakamugi No. 1) were germinated on wet filter paper and transferred into the standard hydroponic culture solution (Mori and Nishizawa, 1987) in a glass house at natural temperature under natural light. The pH of the hydroponic culture solution was adjusted at 5.5 by 0.5 N HCl everyday. When the third leaves developed, the plants were transferred to the hydroponic culture solution without containing Fe. The pH was maintained at 7.0 by 0.5 N NaOH everyday. The control plants were also cultured in the standard culture solution continuously. The culture solution was renewed once in every week. Two weeks after starting Fe-deficient treatment, when severe iron chlorosis significantly appeared on the 4th and 5th leaves, roots were harvested and frozen in liquid N_2 and stored at $-80^\circ C$. until use.

Example 2

Assay of Nicotianamine Synthase Activity

Modified assay method reported previously by the present inventors (Higuchi et al. 1996a) was used. Enzyme solutions

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were equilibrated with reaction buffer [50 mM Tris, 1 mM EDTA, 3 mM dithiothreitol (hereinafter designates as DTT), 10 μ M (p-amidinophenyl) methanesulfonyl fluoride (hereinafter designates as p-APMSF) and 10 μ M trans-epoxysuccinyl-leucylamido-(4-guanidino) butane (hereinafter designates as E-64), pH 8.7]. Buffer exchange was performed by using ultrafiltration unit, Ultrafree C3LGC NMWL10000 (Millipore Co.). S-adenosylmethionine labeled with 14 C in carboxyl group (Amersham Inc.) was added to the enzyme solution at the final concentration of 20 μ M and kept at 25° C. for 15 minutes. The reaction products were separated by thin layer chromatography on silica gel LK6 (Whatman Inc.) using developer (phenol:butanol:formic acid:water=12:3:2:3). Radioactivity of the reaction products was detected by image Analyzer BAS-2000 (Fuji Film Co.). The protein content was assayed by Bradford method using Protein Assay Kit (Bio Rad Inc.).

Example 3

Purification of Nicotianamine Synthase

The following operations were performed at 4° C. and E-64 was added to fractions containing nicotianamine synthase at the final concentration of 10 μ M.

The frozen roots were crushed into a fine powder in liquid N₂ and homogenized in a household juicer with 200 ml of extraction buffer [0.2 M Tris, 10 mM EDTA, 5% (v/v) glycerol, 10 mM DTT, 0.1 mM E-64, 0.1 mM p-APMSF and 5% (w/v) insoluble polyvinylpyrrolidone (PVP), pH 8.0] per 100 g of roots. The homogenate was centrifuged for 30 minutes at 22,500 \times g to obtain supernatant. Ammonium sulfate was added to the supernatant to yield a final concentration of 0.4 M and allowed to stand for 1 hour. Again, the mixture was centrifuged for 30 minutes at 22,500 \times g to obtain supernatant.

The supernatant was loaded onto a TSK gel Butyl Toyopearl 650M column (10 ml bed volume per 100 g of roots), equilibrated with the adsorption buffer [20 mM Tris, 1 mM EDTA, 3 mM DTT, 0.4 M (NH₄)₂SO₄ and 0.1 mM p-APMSF, pH 8.0] and eluted with elution buffer [10 mM Tris, 1 mM EDTA, 3 mM DTT, 0.1 mM p-APMSF, 5% glycerol and 0.05% 3-[(3-chloramidopropyl) dimethylammonio]propanesulfonic acid (hereinafter designates as CHAPS), pH 8.0].

KCl was added to the active fraction to give a final concentration of 0.4 M, and 1 M potassium phosphate buffer (pH 8.0) was added to a final concentration of 1 mM of KCl. A hydroxyapatite 100–350 mesh (Nacalai Tesque), equilibrated with the adsorption buffer (1 mM K—P, 10 mM KCl, 3 mM DTT and 0.1 mM p-APMSF, pH 8.0), was prepared at 10 ml per protein 100 mg and the fractions containing nicotianamine synthase were loaded. Nicotianamine synthase was passed through without adsorption. The passed through fraction was loaded onto TSK gel Butyl Toyopearl 650M column (1 ml bed volume per 10 mg of protein), and nicotianamine synthase was eluted in the manner described above.

The active fraction was loaded onto a DEAE-Sepharose FF column (5 ml bed volume per 25 mg of protein, Pharmacia) equilibrated with the adsorption buffer (20 mM Tris, 1 mM EDTA, 3 mM DTT, 0.1 mM p-APMSF and 0.05% CHAPS, pH 8.0) and eluted with stepwise gradient elution of potassium chloride concentration of 0.05 M, 0.1 M, 0.15 M and 0.2 M. Nicotianamine synthase was eluted at 0.15 M of KCl concentration.

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The active fraction was loaded onto the Ether Toyopearl 650M column (10 ml bed volume per 100 g of roots), equilibrated with adsorption buffer [20 mM Tris, 1 mM EDTA, 3 mM DTT, 1.2 M (NH₄)₂SO₄ and 0.1 mM p-APMSF, pH 8.0]. Nicotianamine synthase was not adsorbed and passed through from the column. The passed through fraction was loaded onto TSK gel Butyl Toyopearl 650M column and fractions containing nicotianamine synthase was eluted. The peptides in the active fraction containing nicotianamine synthase, which was purified by the above column chromatographic treatments, were separated by sodium dodecyl sulfate—polyacrylamide gel electrophoresis (hereinafter designates as SDS-PAGE) using 11% acrylamide slab gels. After SDS-PAGE the gel was stained with 0.3 M copper chloride (Dzandu et al. 1988), and the separated bands were cut out. The gel fragments were destained with 0.25 M EDTA/0.25 M Tris (pH 9.0) and homogenized with the extraction buffer (1% SDS, 25 mM Tris and 192 mM glycine). Each homogenate was electroeluted with SDS-free buffer (25 mM Tris and 192 mM glycine) and peptide was recovered.

Example 4

Determination of Partial Amino Acid Sequence

The isolated nicotianamine synthase was digested chemically with cyanogen bromide (Gross 1967).

After SDS-PAGE treatment, 10-fold volume of 70% (v/v) formic acid and 1% (w/v) cyanogen bromide were added to gel fragments containing nicotianamine synthase and decomposed at 4° C. for overnight. After completion of digestion, the liquid part was collected and dried in vacuo. The dried substance was dissolved in SDS-PAGE sample buffer, and allowed to stand at room temperature for overnight, then the digested product was separated by SDS-PAGE using 16.5% acrylamide gel containing Tricine (Schagger and Jagow, 1987). The peptides were transferred onto a PVDF membrane by electroblotting (Towbin et al. 1979) and stained with amido black. The stained bands were cut out and the amino acid sequence was determined from N-terminal side of each peptide by Edman degradation in gas-phase sequencer (model 492A protein sequencer, Applied Biosystems Inc.).

Example 5

Cloning of Nicotianamine Synthase Genes

PCR amplification was conducted for cDNA originated from Fe-deficient barley roots using primers, which were synthesized based on the obtained partial amino acid sequence. A pYH23 cDNA library prepared from the poly (A)⁺RNA of Fe-deficient barley roots was screened with the thus obtained DNA fragments of PCR product, which was labeled with [α -³²P]dATP using the random primer kit (Takara Shuzo Co.), as the primers. The isolated cDNA clones were sequenced by cycle sequencing kit (Shimadzu Bunko Co.) using Shimadzu DNA sequencer DSQ-2000L.

PCR amplification was conducted for genomic DNA of *Arabidopsis thaliana* using primers, which were synthesized based on nucleotide sequences of AC003114 and AB005245 of *Arabidopsis thaliana*. The thus obtained DNA fragments were sequenced by cycle sequencing kit (Shimadzu Bunko Co.) using Shimadzu DNA sequencer DSQ-1000L.

The determined nucleotide sequence is shown in SEQ ID NO: 2.

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Example 6

Expression of NAS1 Protein in *E. Coli*

A fragment, in which EcoRI site was introduced into the upstream of the first ATG of the HvNAS1 cDNA and PstI and BamHI sites were introduced into the downstream of the stop codon of the HvNAS1 cDNA, was amplified by PCR. The thus obtained amplified product was subcloned in the pBluescriptII SK—using EcoRI site and BamHI site, and the correct nucleotide sequence was confirmed. The fragment between EcoRI site and PstI site was cloned into pMAL-c2 to make expression in the form of fusing the HvNAS1 to the C-terminal of maltose binding protein.

A fragment, in which EcoRI site was introduced into the upstream of the first ATG of the OsNAS1 and HindIII site was introduced into the downstream of the stop codon of the OsNAS1, was amplified by PCR. The thus obtained amplified product was subcloned in the pBluescriptII SK—using EcoRI site and HindIII site, and the correct nucleotide sequence was confirmed. The fragment between EcoRI site and HindIII site was cloned into pMAL-c2 to make expression in the form of fusing the OsNAS1 to the C-terminal of maltose binding protein.

A fragment, in which EcoRI site was introduced into the upstream of the first ATG of the AtNAS1, AtNAS2 and AtNAS3 and XbaI site was introduced into the downstream of the stop codon of the AtNAS1, AtNAS2 and AtNAS3, was amplified by PCR. The thus obtained amplified products were subcloned in the pBluescriptII SK-, and the correct nucleotide sequences were confirmed. The fragment between EcoRI site and XbaI site was cloned into pMAL-c2 to make expression in the form of fusing the AtNAS1, AtNAS2 and AtNAS3 to the C-terminal of maltose binding proteins, respectively.

E. coli strain XL1-Blue was used as a host for expressing the said fused protein. pMAL-c2-HvNAS1 and pMAL-c2, respectively, were introduced into XL1-Blue. The thus obtained recombinant bacteria were cultured in LB medium containing ampicillin and tetracycline, each 50 µg/ml, at 37° C. until the OD 600 of the culture reached 0.5. Isopropyl β-D-thiogalactopyranoside (IPTG) was added to the final concentration of 0.3 mM, and continuously cultured at 37° C. for 3 hours, and collected bacterial cells. Cells were suspended in 10 mM Tris buffer containing 0.2 M NaCl, 1 mM EDTA, 3 mM DTT and 0.1 mM E-64, pH 7.4 and frozen with liquid nitrogen. This was melted in ice water and ultrasonication for 15 seconds was repeated for 10 times. Nicotianamine synthase activity of the thus obtained crude extract was assayed according to the method described in example 2 and the enzyme activity was confirmed.

Example 7

Northern Hybridization

Northern hybridization of barley RNA was performed using DNA fragment, which was prepared by cutting HvNAS 1 cDNA with HindIII and NotI and labeled with [α -³²P]dATP, as a probe. Total RNA was extracted from barley (Naito et al. 1988). The extracted RNA was separated by 1.4% agarose gel electrophoresis, and blotted onto Hybond-N⁺ membranes (Amersham). Northern hybridization of rice RNA was performed using OsNAS1 ORF, which was labeled with [α -³²P]dATP, as a probe. Total RNA was extracted from rice. The extracted RNA was separated by 1.4% agarose gel electrophoresis, and blotted onto Hybond-

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N⁺ membranes (Amersham). The membrane was hybridized with the probe in 0.5 M Church phosphate buffer (Church and Gilbert 1984), 1 mM EDTA, 7% (w/v) SDS with 100 µg/ml salmon sperm DNA at 65° C. for overnight. The membrane was washed with buffer containing 40 mM Church phosphate buffer and 1% (w/v) SDS at 65° C. for 10 minutes. After the washing was repeated once again, the membrane was washed with buffer containing 0.2×SSPE and 0.1% (w/v) SDS at 65° C. for 10 minutes. Radioactivity was detected using the image analyzer BAS-2000.

Results are shown in FIG. 9 and FIG. 16.

Example 8

Southern Hybridization

Genomic DNA was extracted from leaves of barley and rice. The extract was digested with BamHI, EcoRI or HindIII, separated on a 0.8% (w/v) agarose gel electrophoresis, and transferred onto Hybond-N⁺ membranes (Amersham). The hybridization was performed according to the method described in example 7 and radioactivity was detected.

Result is shown in FIG. 10.

Example 9

Preparation of polyclonal antibody

Two rats were immunized using the antigen containing about 100 µg of isolated nicotianamine synthase. The antigen was the same sample as that determined the partial amino acid sequence. The complete Freund's adjuvant was used at the first immunization and the incomplete Freund's adjuvant was used since the second immunization. All the constituents of the blood were corrected after the rats were immunized four times, and the obtained serum was preserved at -80°C.

Example 10

Western blotting analysis

Total protein was extracted using trichloroacetic acid and acetone (Damerval et al. 1986). The plants were crashed in the liquid nitrogen until powder was obtained, and mixed with acetone containing 0.1% (v/v) 2-mercaptoethanol. The protein was precipitated by allowing to stand at -20° C. for 1 hour, and the precipitate was collected by centrifugation at 16,000×g for 30 minutes. The precipitate was suspended in acetone containing 0.1% (v/v) 2-mercaptoethanol and allowed to stand at -20° C. for 1 hour, then collected the precipitate by centrifugation at 16,000×g for 30 minutes. The precipitate was dried in vacuo, and dissolved in the sample buffer [9.5 M urea, 2% (w/v) Triton X-100 and 5% (v/v) 2-ME], then centrifuged at 16,000×g for 10 minutes to obtain the supernatant. The proteins contained in the supernatant were separated by SDS-PAGE or the denaturing two-dimensional electrophoresis (O' Farrell 1975) and transferred onto PVDF membrane. Western blotting analysis was performed by applying the primary antibody containing anti-nicotianamine synthase antibody prepared in example 9 and the secondary antibody containing horse radish binding anti-mouse IgG (H+L) goat antibody (Wako Pure Chemicals Co.) on the membrane and coloring with diaminobenzidine.

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Result is shown in FIG. 12. SDS-PAGE was performed using 12.5% acrylamide slab gel. Protein 100 µg was electrophoresed. Proteins of roots 200 µg and leaves 500 µg were electrophoresed.

Example 11

RT-PCR

Total RNA was extracted from *Arabidopsis thaliana*. RT-PCR was performed with 1 µg RNA as a template by using the EZ rTh RNA PCR kit (Parkin Elmer Inc.). Specific primers for AtNAS1, AtNAS2 and AtNAS3, respectively, were used.

Result is shown in FIG. 18.

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INDUSTRIAL APPLICABILITY

Various cells are transformed according to the conventional method by using recombinant vectors of the present invention. Mass production of nicotianamine can be performed by using the obtained transformant. These methods can be performed according to the method known in the person skilled in the art.

Selective breeding of plants, preferably graminaceous plants can also be performed using genes of the present invention. Especially, genes of the present invention can be applied for improving varieties, which can grow on Fe-deficient soil.

SEQUENCE LISTING

<160> NUMBER OF SEQ ID NOS: 22

<210> SEQ ID NO 1

<211> LENGTH: 328

<212> TYPE: PRT

<213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 1

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                20             25             30
Glu Val Asp Arg Leu Phe Thr Asp Leu Val Thr Ala Cys Val Pro Pro
          35             40             45
Ser Pro Val Asp Val Thr Lys Leu Ser Pro Glu His Gln Arg Met Arg
          50             55             60
Glu Ala Leu Ile Arg Leu Cys Ser Ala Ala Glu Gly Lys Leu Glu Ala
65             70             75             80
His Tyr Ala Asp Leu Leu Ala Thr Phe Asp Asn Pro Leu Asp His Leu
          85             90             95
Gly Leu Phe Pro Tyr Tyr Ser Asn Tyr Val Asn Leu Ser Arg Leu Glu
          100            105            110
Tyr Glu Leu Leu Ala Arg His Val Pro Gly Ile Ala Pro Ala Arg Val
          115            120            125
Ala Phe Val Gly Ser Gly Pro Leu Pro Phe Ser Ser Leu Val Leu Ala
          130            135            140
Ala His His Leu Pro Glu Thr Gln Phe Asp Asn Tyr Asp Leu Cys Gly
          145            150            155            160
Ala Ala Asn Glu Arg Ala Arg Lys Leu Phe Gly Ala Thr Ala Asp Gly
          165            170            175
Val Gly Ala Arg Met Ser Phe His Thr Ala Asp Val Ala Asp Leu Thr
          180            185            190
Gln Glu Leu Gly Ala Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly
          195            200            205
Met Ala Ala Glu Glu Lys Ala Lys Val Ile Ala His Leu Gly Ala His
          210            215            220
Met Val Glu Gly Ala Ser Leu Val Val Arg Ser Ala Arg Pro Arg Gly
          225            230            235            240
Phe Leu Tyr Pro Ile Val Asp Pro Glu Asp Ile Arg Arg Gly Gly Phe
          245            250            255

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Glu Val Leu Ala Val His His Pro Glu Gly Glu Val Ile Asn Ser Val
 260 265 270
 Ile Val Ala Arg Lys Ala Val Glu Ala Gln Leu Ser Gly Pro Gln Asn
 275 280 285
 Gly Asp Ala His Ala Arg Gly Ala Val Pro Leu Val Ser Pro Pro Cys
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 Asn Phe Ser Thr Lys Met Glu Ala Ser Ala Leu Glu Lys Ser Glu Glu
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 Leu Thr Ala Lys Glu Leu Ala Phe
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<210> SEQ ID NO 2
 <211> LENGTH: 1295
 <212> TYPE: DNA
 <213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 2

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gccgagctgc cgtcgtgag cccgtcccc gaggtcgaca ggctcttccac cgacctcgtc    180
acggcctgcg tcccgccgag ccccgctgac gtgacgaagc tcagcccgga gcaccagagg    240
atgcgggagg ctctcatccg cttgtgctcc gccgccgagg ggaagctcga ggcgcactac    300
gccgacctgc tcgccacctt cgacaaccg ctcgaccacc tcggcctctt cccgtactac    360
agcaactacg tcaacctcag caggctggag tacgagctcc tggcgcgcca cgtgccgggc    420
atcgcgccgg cgcgctgctc ctctctggc tccgccccg tgccgttcag ctctctctc    480
ctcgccgctc accacctgcc cgagaccag ttcgacaact acgacctgtg cggcgcggcc    540
aacgagcgcg ccaggaagct gttcggcgcg acggcggacg gcgtcggcgc gcgtatgtcg    600
ttccacacgg cggacgtcgc cgacctcacc caggagctcg gcgcctacga cgtggtcttc    660
ctcgccgctc tcgtcggcat ggcagccgag gagaaggcca aggtgattgc ccacctgggc    720
gcgcacatgg tggagggggc gtccttggtc gtgctggagcg cacggccccg cggtttctt    780
taccctattg tcgaccgga ggacatcagg cggggtgggt tcgaggtgct ggccgtgac    840
caccgggaag gtgaggtgat caactctgtc atcgtgccc gtaaggcgt cgaagcgag    900
ctcagtgggc cgcagaacgg agacgcgcac gcacggggcg cggtgccgtt ggtcagccc    960
ccatgcaact tctccaccaa gatggaggcg agcgcgcttg agaagagcga ggagctgacc   1020
gcaaagagc tggccttttg attgaagat gcgctggtc attctgtcgc ctgcatcgt    1080
ggtaactttc ctactctgtg gtgtttgat gtttgtgcct gtaagagtta tgcttcggc    1140
cttctgctgt taatttacac gcgttacatg tagtacttgt atttatacct ggaataacgg   1200
tatgtaacat aaatattagt gggattttaa gtgtaatgct aaataataag aaaacttgat   1260
gcagacattc aaaaaaaaaa aaaaaaaaaa aaaaa                                1295
    
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<210> SEQ ID NO 3
 <211> LENGTH: 335
 <212> TYPE: PRT
 <213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 3

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 1 5 10 15

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Thr	Gly	Leu	His	Ala	Ala	Ile	Ala	Lys	Leu	Pro	Ser	Leu	Ser	Pro	Ser
			20					25					30		
Pro	Asp	Val	Asp	Ala	Leu	Phe	Thr	Glu	Leu	Val	Thr	Ala	Cys	Val	Pro
		35					40					45			
Pro	Ser	Pro	Val	Asp	Val	Thr	Lys	Leu	Gly	Pro	Glu	Ala	Gln	Glu	Met
		50					55				60				
Arg	Glu	Gly	Leu	Ile	Arg	Leu	Cys	Ser	Glu	Ala	Glu	Gly	Lys	Leu	Glu
65					70					75					80
Ala	His	Tyr	Ser	Asp	Met	Leu	Ala	Ala	Phe	Asp	Lys	Pro	Leu	Asp	His
					85				90					95	
Leu	Gly	Met	Phe	Pro	Tyr	Tyr	Asn	Asn	Tyr	Ile	Asn	Leu	Ser	Lys	Leu
			100						105					110	
Glu	Tyr	Glu	Leu	Leu	Ala	Arg	Tyr	Val	Pro	Gly	Gly	Tyr	Arg	Pro	Ala
			115						120					125	
Arg	Val	Ala	Phe	Ile	Gly	Ser	Gly	Pro	Leu	Pro	Phe	Ser	Ser	Phe	Val
							135							140	
Leu	Ala	Ala	Arg	His	Leu	Pro	Asp	Thr	Met	Phe	Asp	Asn	Tyr	Asp	Leu
145					150					155					160
Cys	Gly	Ala	Ala	Asn	Asp	Arg	Ala	Ser	Lys	Leu	Phe	Arg	Ala	Asp	Arg
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Asp	Val	Gly	Ala	Arg	Met	Ser	Phe	His	Thr	Ala	Asp	Val	Ala	Asp	Leu
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Ala	Gly	Glu	Leu	Ala	Lys	Tyr	Asp	Val	Val	Phe	Leu	Ala	Ala	Leu	Val
									200					205	
Gly	Met	Ala	Ala	Glu	Asp	Lys	Ala	Lys	Val	Ile	Ala	His	Leu	Gly	Ala
														210	
His	Met	Ala	Asp	Gly	Ala	Ala	Leu	Val	Val	Arg	Ser	Ala	His	Gly	Ala
225					230					235					240
Arg	Gly	Phe	Leu	Tyr	Pro	Ile	Val	Asp	Pro	Gln	Asp	Ile	Gly	Arg	Gly
					245					250					255
Gly	Phe	Glu	Val	Leu	Ala	Val	Cys	His	Pro	Asp	Asp	Asp	Val	Val	Asn
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Ser	Val	Ile	Ile	Ala	Gln	Lys	Ser	Lys	Asp	Val	His	Ala	Asp	Gly	Leu
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Gly	Ser	Gly	Arg	Gly	Ala	Gly	Gly	Gln	Tyr	Ala	Arg	Gly	Thr	Val	Pro
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Val	Val	Ser	Pro	Pro	Cys	Arg	Phe	Gly	Glu	Met	Val	Ala	Asp	Val	Thr
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Gln	Asn	His	Lys	Arg	Asp	Glu	Phe	Ala	Asn	Ala	Glu	Val	Ala	Phe	
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<210> SEQ ID NO 4

<211> LENGTH: 1342

<212> TYPE: DNA

<213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 4

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tcgctcagcc catccccgga cgtogacgcg ctcttcacgg agctggtcac ggcgtgogtt	180
ccaccgagtc cagtggacgt gaccaagctc gggccggagg cgcaggagat gcgggagggc	240
ctcatccgcc tatgctccga ggcgagggg aagctggagg cgcaactctc cgacatgctc	300
gccgccttcg acaagccgct ggatcacctc ggcattgtcc cctactacaa caactacatc	360

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cgccacctgc ccgacacccat gttcgacaac tatgacctgt gcggtgcggc caacgatcgc 540
gccagcaagc tcttcocgcg ggatcgcgac gtgggtgccc gcatgtcgtt ccacacggcc 600
gacgtcgcgg acctcgcggc cgagctcgcc aagtacgacg ttgtcttctt ggccgcactc 660
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tgtgtacaag tgaattttaa ttcacaagta catataatgg tcaccattga aaagatgttt 1260
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<210> SEQ ID NO 5

<211> LENGTH: 335

<212> TYPE: PRT

<213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 5

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 35          40          45
Pro Pro Ser Pro Val Asp Val Thr Lys Leu Gly Pro Glu Ala Gln Glu
 50          55          60
Met Arg Glu Gly Leu Ile Arg Leu Cys Ser Glu Ala Glu Gly Lys Leu
 65          70          75          80
Glu Ala His Tyr Ser Asp Met Leu Ala Ala Phe Asp Asn Pro Leu Asp
 85          90          95
His Leu Gly Ile Phe Pro Tyr Tyr Ser Asn Tyr Ile Asn Leu Ser Lys
100          105          110
Leu Glu Tyr Glu Leu Leu Ala Arg Tyr Val Arg Arg His Arg Pro Ala
115          120          125
Arg Val Ala Phe Ile Gly Ser Gly Pro Leu Pro Phe Ser Ser Phe Val
130          135          140
Leu Ala Ala Arg His Leu Pro Asp Thr Met Phe Asp Asn Tyr Asp Leu
145          150          155          160
Cys Gly Ala Ala Asn Asp Arg Ala Ser Lys Leu Phe Arg Ala Asp Thr
165          170          175
Asp Val Gly Ala Arg Met Ser Phe His Thr Ala Asp Val Ala Asp Leu
180          185          190

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Ala Ser Glu Leu Ala Lys Tyr Asp Val Val Phe Leu Ala Ala Leu Val
 195 200 205

Gly Met Ala Ala Glu Asp Lys Ala Lys Val Ile Ala His Leu Gly Ala
 210 215 220

His Met Ala Asp Gly Ala Ala Leu Val Val Arg Ser Ala His Gly Ala
 225 230 235 240

Arg Gly Phe Leu Tyr Pro Ile Val Asp Pro Gln Asp Ile Gly Arg Gly
 245 250 255

Gly Phe Glu Val Leu Ala Val Cys His Pro Asp Asp Asp Val Val Asn
 260 265 270

Ser Val Ile Ile Ala Gln Lys Ser Lys Glu Val His Ala Asp Gly Leu
 275 280 285

Gly Ser Ala Arg Gly Ala Gly Arg Gln Tyr Ala Arg Gly Thr Val Pro
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Val Val Ser Pro Pro Cys Arg Phe Gly Glu Met Val Ala Asp Val Thr
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Gln Asn His Lys Arg Asp Glu Phe Ala Asn Ala Glu Val Ala Phe
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<210> SEQ ID NO 6
 <211> LENGTH: 1314
 <212> TYPE: DNA
 <213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 6

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cgtcgtctcag cccatccccg gacgtcgacg cgctcttcac cgagctggtc acggcgtgcg    180
ttcccccgag ccccgtagac gtgaccaagc tcggccccga ggcgcaggag atgcgggagg    240
gectcatccg cctctgtccc gaggccgagg ggaagctgga ggcgcactac tccgacatgc    300
tcgcccctt cgacaaccgg ctggatcacc tcggcatctt ccctactac agcaactaca    360
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ccccgtgcag gttcggtag atggtggcgg atgtgacca gaaccacaag agagacgagt    1020
ttgccaacgc cgaagtggcc tttgatcga tcgtcgccaa gggacaataa atgaactggg    1080
atgtgtagg gtaatttggc tacctcgtc cttgatcgtc tgcaatatgt gcacattttc    1140
ctactaccgc tgcttatgca tttcaagcca tgtgatgttg gtatccaata aagtatgtgt    1200
agggtttaca cgaaatgtc tttacacctt gtacgtgtaa gtgttgacia cgatgaattt    1260
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<212> TYPE: PRT
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Asp Val Asp Ala Leu Phe Thr Asp Leu Val Thr Ala Cys Val Pro Pro
 35                               40          45
Ser Pro Val Asp Val Thr Lys Leu Ala Pro Glu Ala Gln Ala Met Arg
 50                               55          60
Glu Gly Leu Ile Arg Leu Cys Ser Glu Ala Glu Gly Lys Leu Glu Ala
 65                               70          75          80
His Tyr Ser Asp Met Leu Ala Ala Phe Asp Asn Pro Leu Asp His Leu
 85                               90
Gly Val Phe Pro Tyr Tyr Ser Asn Tyr Ile Asn Leu Ser Lys Leu Glu
 100                              105          110
Tyr Glu Leu Leu Ala Arg Tyr Val Pro Gly Arg His Arg Pro Ala Arg
 115                              120          125
Val Ala Phe Ile Gly Ser Gly Pro Leu Pro Phe Ser Ser Tyr Val Leu
 130                              135          140
Ala Ala Arg His Leu Pro Asp Thr Val Phe Asp Asn Tyr Asp Leu Cys
 145                              150          155          160
Gly Ala Ala Asn Asp Arg Ala Thr Arg Leu Phe Arg Ala Asp Lys Asp
 165                              170          175
Val Gly Ala Arg Met Ser Phe His Thr Ala Asp Val Ala Asp Leu Thr
 180                              185          190
Asp Glu Leu Ala Thr Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly
 195                              200          205
Met Ala Ala Glu Asp Lys Ala Lys Val Ile Ala His Leu Gly Ala His
 210                              215          220
Met Ala Asp Gly Ala Ala Leu Val Ala Arg His Gly Ala Arg Gly Phe
 225                              230          235          240
Leu Tyr Pro Ile Val Asp Pro Gln Asp Ile Gly Arg Gly Gly Phe Glu
 245                              250          255
Val Leu Ala Val Cys His Pro Asp Asp Asp Val Val Asn Ser Val Ile
 260                              265          270
Ile Ala Gln Lys Ser Asn Asp Val His Glu Tyr Gly Leu Gly Ser Gly
 275                              280          285
Arg Gly Gly Arg Tyr Ala Arg Gly Thr Val Val Pro Val Val Ser Pro
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<210> SEQ ID NO 8
<211> LENGTH: 1249
<212> TYPE: DNA
<213> ORGANISM: Hordeum vulgare L.

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<400> SEQUENCE: 8

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cggaggcgca ggcgatgcgg gagggcctca tccgcctctg ctccgaggcc gagggcaagc    300
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gtacagtgcc cggcaggcat cgcccggccc gcgtcgcctt catcggctcc ggcccgtgc    480
cgttcagctc ctactgctc gccgcgcgcc acctgcccga caccgtgttc gacaactacg    540
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gcgccgcat gtcgttccac accgcccagc tcgcggaact caccgacgag ctcgctacgt    660
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acgacgtgca cgagtatgga cttggcagcg ggcgtggtgg acggtacgcg cgaggcacgg    960
tggtgccggt ggtcagccca cctgcaggt tcggcgagat ggtggcagac gtgaccaga    1020
agagagagga gtttgcaac gcggaagtgg ccttctgatt gctgctgaat cgcttctgat    1080
cgtacgtggt aatttttcta ctactctcc tcctaccacc acctatcacc tatgtatgca    1140
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aaaaaaaaa aaaaaaaaaa aaaaaaaaaa aaaaaaaaaa aaaaaaaaaa    1249

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<210> SEQ ID NO 9

<211> LENGTH: 282

<212> TYPE: PRT

<213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 9

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Met Glu Ala Glu Asn Gly Glu Val Ala Ala Leu Val Glu Lys Ile Thr
  1             5             10             15
Gly Leu His Ala Ala Ile Ser Lys Leu Pro Ala Leu Ser Pro Ser Pro
  20             25             30
Gln Val Asp Ala Leu Phe Thr Glu Leu Val Ala Ala Cys Val Pro Ser
  35             40             45
Ser Pro Val Asp Val Thr Lys Leu Gly Pro Glu Ala Gln Glu Met Arg
  50             55             60
Gln Asp Leu Ile Arg Leu Cys Ser Ala Ala Glu Gly Leu Leu Glu Ala
  65             70             75             80
His Tyr Ser Asp Met Leu Thr Ala Leu Asp Ser Pro Leu Asp His Leu
  85             90             95
Gly Arg Phe Pro Tyr Phe Asp Asn Tyr Val Asn Leu Ser Lys Leu Glu
  100            105            110
His Asp Leu Leu Ala Gly His Val Ala Ala Pro Ala Arg Val Ala Phe
  115            120            125
Ile Gly Ser Gly Pro Leu Pro Phe Ser Ser Leu Phe Leu Ala Thr Tyr
  130            135            140
His Leu Pro Asp Thr Arg Phe Asp Asn Tyr Asp Arg Cys Ser Val Ala
  145            150            155            160

```

-continued

Asn Gly Arg Ala Met Lys Leu Val Gly Ala Ala Asp Glu Gly Val Arg
 165 170 175
 Ser Arg Met Ala Phe His Thr Ala Glu Val Thr Asp Leu Thr Ala Glu
 180 185 190
 Leu Gly Ala Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly Met Thr
 195 200 205
 Ser Lys Glu Lys Ala Asp Ala Ile Ala His Leu Gly Lys His Met Ala
 210 215 220
 Asp Gly Ala Val Leu Val Arg Glu Ala Leu His Gly Ala Arg Ala Phe
 225 230 235 240
 Leu Tyr Pro Val Val Glu Leu Asp Asp Val Gly Arg Gly Gly Phe Gln
 245 250 255
 Val Leu Ala Val His His Pro Ala Gly Asp Glu Val Phe Asn Ser Phe
 260 265 270
 Ile Val Ala Arg Lys Val Lys Met Ser Ala
 275 280

<210> SEQ ID NO 10
 <211> LENGTH: 1044
 <212> TYPE: DNA
 <213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 10

```

gtgacatgga ggccgaaaac ggcgaggtgg ctgctctggt cgagaagatc accggtctcc    60
acgccgccat ctccaagctc ccggcactaa gcccgctctcc tcaagtcgac gcgctcttca    120
ccgagctggt tgcggcgtgc gtcccatcaa gcccggtgga cgtgaccaag ctcggcccgg    180
aggcgcagga gatcggcgag gacctcatcc gtctctgctc gcccgccgag gggctgctcg    240
aggcgcacta ctccgacatg ctaccgcgt tggacagccc gctcgaccac ctcggccgct    300
tcccttactt cgacaactac gtaaacctca gcaagctcga gcacgatctt ctggcaggtc    360
acgtggcggc cccggcccgc gtggcggttca tcgggtcggg gccactgccg ttcagctcgc    420
tcttccttgc gacgtaccac ctgccggaca cccggttcga caactacgac cgggtgcagcg    480
tggcgaatgg ccgggcgatg aagctggctg gcgcggcgga cgagggcgtg cgatcacgca    540
tggcggtcca cacggccgaa gtcacggacc tcacggctga gctcggcgt tacgacgtgg    600
tcttcctggc cgcgctcgtg ggaatgacgt ccaaggagaa ggccgacgcc atagcgcact    660
tggggaagca catggcagat ggggcgggtg tcgtgcgcga agcgtgcac ggggcgcgag    720
cgttcctgta tcctgtcgtg gagctggacg atgtcgggcg tgggtgggttc caagtctggtg    780
ccgtgcacca ccctgcaggc gatgaggtgt tcaactcatt catagttgcc cggaaggtga    840
aatgagtgct ttaaattaag aaaaggtgga gcctgtctgc ttgtgcaaat ggtgtctcac    900
attgataata accagatgat accctgcaca ttgatggggg tactgcagta tgtttcaatg    960
aggctctggt gtatcaaata tgagtattg gcttaataat atcagcgaat atgtttcgat   1020
taaaaaaaaa aaaaaaaaaa aaaa                                           1044
    
```

<210> SEQ ID NO 11
 <211> LENGTH: 328
 <212> TYPE: PRT
 <213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 11

Met Asp Ala Gln Asn Lys Glu Val Asp Ala Leu Val Gln Lys Ile Thr
 1 5 10 15

-continued

Gly Leu His Ala Ala Ile Ala Lys Leu Pro Ser Leu Ser Pro Ser Pro
 20 25 30
 Asp Val Asp Ala Leu Phe Thr Asp Leu Val Thr Ala Cys Val Pro Pro
 35 40 45
 Ser Pro Val Asp Val Thr Lys Leu Gly Ser Glu Ala Gln Glu Met Arg
 50 55 60
 Glu Gly Leu Ile Arg Leu Cys Ser Glu Ala Glu Gly Lys Leu Glu Ala
 65 70 75 80
 His Tyr Ser Asp Met Leu Ala Ala Phe Asp Asn Pro Leu Asp His Leu
 85 90 95
 Gly Met Phe Pro Tyr Tyr Ser Asn Tyr Ile Asn Leu Ser Lys Leu Glu
 100 105 110
 Tyr Glu Leu Leu Ala Arg Tyr Val Pro Gly Gly Ile Ala Arg Pro Ala
 115 120 125
 Val Ala Phe Ile Gly Ser Gly Pro Leu Pro Phe Ser Ser Tyr Val Leu
 130 135 140
 Ala Ala Arg His Leu Pro Asp Ala Met Phe Asp Asn Tyr Asp Leu Cys
 145 150 155 160
 Ser Ala Ala Asn Asp Arg Ala Ser Lys Leu Phe Arg Ala Asp Lys Asp
 165 170 175
 Val Gly Ala Arg Met Ser Phe His Thr Ala Asp Val Ala Asp Leu Thr
 180 185 190
 Arg Glu Leu Ala Ala Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly
 195 200 205
 Met Ala Ala Glu Asp Lys Ala Lys Val Ile Pro His Leu Gly Ala His
 210 215 220
 Met Ala Asp Gly Ala Ala Leu Val Val Arg Ser Ala Gln Ala Arg Gly
 225 230 235 240
 Phe Leu Tyr Pro Ile Val Asp Pro Gln Asp Ile Gly Arg Gly Gly Phe
 245 250 255
 Glu Val Leu Ala Val Cys His Pro Asp Asp Asp Val Val Asn Ser Val
 260 265 270
 Ile Ile Ala His Lys Ser Lys Asp Val His Ala Asn Glu Arg Pro Asn
 275 280 285
 Gly Arg Gly Gly Gln Tyr Arg Gly Ala Val Pro Val Val Ser Pro Pro
 290 295 300
 Cys Arg Phe Gly Glu Met Val Ala Asp Val Thr His Lys Arg Glu Glu
 305 310 315 320
 Phe Thr Asn Ala Glu Val Ala Phe
 325

<210> SEQ ID NO 12
 <211> LENGTH: 1352
 <212> TYPE: DNA
 <213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 12

ctccacttcg ctccgtgtgcc tcaggtagcc acaacataca gtattaaaat ggatgcccag 60
 aacaaggagg ttgatgcctt ggtccagaag atcaccggcc tccacgccgc catcgccaag 120
 ctgccgtccc tcagcccata acccgacgtc gacgcgctct tcaccgacct ggtcaccgcg 180
 tgggtccccc cgagcccctt ggagctgacc aagctcgggt cggaggcgca ggagatgagg 240
 gagggcctca tccgcctctg ctccgaggcc gaggggaagc tggaggcgca ctactccgac 300

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```

atgctggccg ccttcgacaa cccgctcgac cacctcgga tgttccccta ctacagcaac 360
tacatcaacc tcagcaagct ggagtagcag ctccctggcgc gctacgtgcc gggcgccatc 420
gcccggcccg ctgtcgcggt catcgctcc gccccgctgc cgttcagctc ctacgtcctc 480
gcccgtcgcg acctgcccga cgccatgttc gacaactacg acctgtgtag cgcggccaac 540
gaccgtgcga gcaagctggt ccgcgccgac aaggacgtgg gcgcccgcac gtctttccac 600
accgcccagc tagcggacct caccgcgag ctccgcccgt acgacgtcgt cttcctggcc 660
gcgctcgtgg gcatggctgc cgaggacaag gcccaaggta ttccgcacct cggcgcgcac 720
atggcggcag gggcgccct cgtcgtcgc agtgcgcagg cacgtgggtt cctctacccg 780
atcgtcagtc cccaggacat cggtcgaggc gggtttgagg tgctggccgt gtgtcacccc 840
gacgatgacg tggtaactc cgtcatcacc gcacacaagt ccaaggacgt gcatgccaat 900
gaacgtccca acgggctggt tggacagtac cggggcgcgg taccggtggt cagcccgcg 960
tgcaggttcg gtgagatggt ggcggcagtg acccacaaga gagaggagtt caccaacgcg 1020
gaagtggcct tctgatcgtt gcgagggaaat gaaaatgaag gtggacgtgt gtggtcagca 1080
tccatcagtg gctgcctgct tcatcgcttg caatcgact actacctacc tatgcagttc 1140
aagtcagtg ttgtcaatgt aagtgtgatg tttacactag tctatgaaag gcagggcaga 1200
cgagggtagt gtgccaahta acagtgtgtc attataggtg taagtgttga gaataagacc 1260
atthttgttc acaaatagta tgatgtaatc ggtgtcatat tcgtattgag tacattgtc 1320
aagttggttg ctaaaaaaaaa aaaaaaaaaa aa 1352

```

<210> SEQ ID NO 13

<211> LENGTH: 329

<212> TYPE: PRT

<213> ORGANISM: Hordeum vulgare L.

<400> SEQUENCE: 13

```

Met Asp Ala Gln Ser Lys Glu Val Asp Ala Leu Val Gln Lys Ile Thr
 1           5           10           15
Gly Leu His Ala Ala Ile Ala Lys Leu Pro Ser Leu Ser Pro Ser Pro
 20           25           30
Asp Val Asp Ala Leu Phe Thr Asp Leu Val Thr Ala Cys Val Pro Pro
 35           40           45
Ser Pro Val Asp Val Thr Lys Leu Ala Pro Glu Ala Gln Ala Met Arg
 50           55           60
Glu Gly Leu Ile Arg Leu Cys Ser Glu Ala Glu Gly Lys Leu Glu Ala
 65           70           75           80
His Tyr Ser Asp Met Leu Ala Ala Phe Asp Asn Pro Leu Asp His Leu
 85           90           95
Gly Val Phe Pro Tyr Tyr Ser Asn Tyr Ile Asn Leu Ser Lys Leu Glu
 100          105          110
Tyr Glu Leu Leu Ala Arg Tyr Val Pro Gly Gly Ile Ala Pro Ala Arg
 115          120          125
Val Ala Phe Ile Gly Ser Gly Pro Leu Pro Phe Ser Ser Tyr Val Leu
 130          135          140
Ala Ala Arg His Leu Pro Asp Thr Val Phe Asp Asn Tyr Val Pro Val
 145          150          155          160
Arg Ala Ala Asn Asp Arg Ala Thr Arg Leu Phe Arg Ala Asp Lys Asp
 165          170          175
Val Gly Ala Arg Met Ser Phe His Thr Ala Asp Val Ala Asp Leu Thr
 180          185          190

```

-continued

Asp Glu Leu Ala Thr Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly
 195 200 205
 Met Ala Ala Glu Asp Lys Gly Gln Gly Asp Pro His Leu Gly Ala His
 210 215 220
 Met Ala Asp Gly Ala Ala Leu Val Arg Ser Ala His Gly Ala Arg Gly
 225 230 235 240
 Phe Leu Tyr Pro Ile Val Asp Pro Gln Asp Ile Gly Arg Gly Gly Phe
 245 250 255
 Glu Val Leu Ala Val Cys His Pro Asp Asp Asp Val Val Asn Ser Val
 260 265 270
 Ile Ile Ala Gln Lys Ser Lys Asp Met Phe Ala Asn Gly Pro Arg Asn
 275 280 285
 Gly Cys Gly Gly Arg Tyr Ala Arg Gly Thr Val Pro Val Val Ser Pro
 290 295 300
 Pro Cys Arg Phe Gly Glu Met Val Ala Asp Val Thr Gln Lys Arg Glu
 305 310 315 320
 Glu Phe Ala Lys Ala Glu Val Ala Phe
 325

<210> SEQ ID NO 14
 <211> LENGTH: 1371
 <212> TYPE: DNA
 <213> ORGANISM: Hordeum vulgare L.
 <220> FEATURE:
 <221> NAME/KEY: misc_feature
 <222> LOCATION: (8)..(8)
 <223> OTHER INFORMATION: n = t, c, a or g

<400> SEQUENCE: 14

ggagcggnac gcgtggcgga ggtgggcact accgtagtac cgtgcctcag agctcatcac 60
 tggtcaggta ccaagaagac ataaaaatgg acgccagag caaggaggtc gacgcccttg 120
 tccagaagat caccggcctc caccgcgcca tcgccaagct gccctcgtc agcccgtccc 180
 cggacgtcga cgcgctcttc accgacctg tcaccgcgtg cgtgcccccg agcccgtgg 240
 acgtgaccaa gctcgcctcg gaggcgcagg cgatcgggga gggcctcctc cgcctctgct 300
 ccgaggccga gggcaagctg gaggcgcact actccgacat gctcgcctcc ttcgacaacc 360
 cgctcgacca cctcggcgtc tccccctact acagcaacta catcaacctc agcaagctcg 420
 agtacgagct cctcgcgcgc tacgtgcccg gcggcatcgc cccggcccgc gtcgcttca 480
 tcggctccgg cccgctcccg ttcagctcct acgtcctcgc cgcgcgccac ctgcccgaca 540
 ccgtgttcga caactacgta cctgtgcgcg cggccaacga ccgcgcgacc aggctgttcc 600
 gcgcggacaa ggagctcggc gcccgcatgt cgttccacac gcccgacgtc gcggacctca 660
 ccgacgagct cgctacgtac gacgtcgtct tcttgcccgc gctcgtgggc atggccgccc 720
 aggacaaggg ccaaggatgat ccgcaccttg gcgcgcacat ggcggacggg gcggccctcg 780
 tccgcagcgc gcacggggcg cgtgggttcc tctaccgat cgtcgcctcc caagacattg 840
 gtcgagggcg gttcgaggtg ctcgcccgtg gtcaccccga cgacgacgtg gtgaactccg 900
 tcatcatcgc gcagaagtct aaggacatgt ttgccaatgg acctcgcaac ggggtgtggtg 960
 gacggtacgc gcgaggcacg gtgcccgttg tcagcccgcc ctgcaggttc ggcgagatgg 1020
 tggcagacgt gaccagaag agagaggagt ttgccaaggc ggaagtggcc ttctgattgc 1080
 tgcgaggta ccatccgtat gccgctgcta cetttaata tcttgcaatc gtaggtggcg 1140
 attttctac tcttgttacg acctttcaaa tcatatggtg tttgtaccga ataagtgaag 1200

-continued

```
tgtgttgctt acacgcgcat gtcttgatca ctcggtctct agaaggcagg gcagatcaag 1260
agactgtgca aaggaaaaga aatgtgtggtt gttgtaggtg tatgagttgg gagtaaatg 1320
attctagttc acaaaaaaaaa aaaaaaaaaa aaaaaaaaaa aaaaaaaaaa a 1371
```

<210> SEQ ID NO 15

<211> LENGTH: 324

<212> TYPE: PRT

<213> ORGANISM: *Oryza sativa* L.

<400> SEQUENCE: 15

```
Met Glu Ala Gln Asn Gln Glu Val Ala Ala Leu Val Glu Lys Ala Gly
  1          5          10          15
Leu His Ala Ala Ser Lys Leu Pro Ser Leu Ser Pro Ser Ala Glu Val
          20          25          30
Asp Ala Leu Phe Thr Asp Leu Val Thr Ala Cys Val Pro Ala Ser Pro
          35          40          45
Val Asp Val Ala Lys Leu Gly Pro Glu Ala Gln Ala Met Arg Glu Glu
          50          55          60
Leu Arg Leu Cys Ser Ala Ala Glu Gly His Leu Glu Ala His Tyr Ala
          65          70          75          80
Asp Met Leu Ala Ala Phe Asp Asn Pro Leu Asp His Leu Ala Arg Phe
          85          90          95
Pro Tyr Tyr Gly Asn Tyr Val Asn Leu Ser Lys Leu Glu Tyr Asp Leu
          100         105         110
Leu Val Arg Tyr Val Pro Gly Ala Pro Thr Arg Val Ala Phe Val Gly
          115         120         125
Ser Gly Pro Leu Pro Phe Ser Ser Leu Val Leu Ala Ala His His Leu
          130         135         140
Pro Asp Ala Val Phe Asp Asn Tyr Asp Arg Cys Gly Ala Ala Asn Glu
          145         150         155         160
Arg Ala Arg Arg Leu Phe Arg Gly Ala Asp Glu Gly Leu Gly Ala Arg
          165         170         175
Met Ala Phe His Thr Ala Asp Val Ala Thr Leu Thr Gly Glu Leu Gly
          180         185         190
Ala Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly Met Ala Ala Glu
          195         200         205
Glu Lys Ala Gly Val Ala His Leu Gly Ala His Met Ala Asp Gly Ala
          210         215         220
Ala Leu Val Val Arg Thr Ala His Gly Ala Arg Gly Phe Leu Tyr Pro
          225         230         235         240
Val Asp Pro Glu Asp Val Arg Arg Gly Gly Phe Asp Val Leu Ala Val
          245         250         255
Cys His Pro Glu Asp Glu Val Asn Ser Val Val Ala Arg Lys Val Gly
          260         265         270
Ala Ala Ala Ala Ala Ala Ala Ala Arg Arg Asp Glu Leu Ala Asp Ser
          275         280         285
Arg Gly Val Val Leu Pro Val Val Gly Pro Pro Ser Thr Cys Cys Lys
          290         295         300
Val Glu Ala Ser Ala Val Glu Lys Ala Glu Glu Phe Ala Ala Asn Lys
          305         310         315         320
Glu Leu Ser Val
```

<210> SEQ ID NO 16

-continued

<211> LENGTH: 1372

<212> TYPE: DNA

<213> ORGANISM: *Oryza sativa* L.

<400> SEQUENCE: 16

```

ctccatttgg ttgtcatttt caactataat ccaccacaac tcgtgcaaca tcagctcact    60
cgtgttccca acccgacaaa agcttcacag atggagggtc agaaccaaga ggtcgctgcc    120
ctggtcgaga agatcgccgg cctccacgcc gccatctcca agctgcccgc gctgagccca    180
tccgccgagg tggacgcgct cttcaccgac ctgcgcacgg cgtgctgccc ggcgagcccc    240
gtcgcagctgg ccaagctcgg cccggaggcg caggcgatgc gggaggagct catccgctc    300
tgctccgccc ccgagggcca cctcgaggcg cactacgccg acatgctcgc cgcttcgac    360
aaccgcctcg accacctcgc ccgcttcccg tactacggca actacgtcaa cctgagcaag    420
ctggagtacg acctcctcgt ccgctacgtc cccggcattg cccccaccg cgtcgcttc    480
gtcgggtcgg gcccgctgcc gttcagctcc ctcgctcctg ctgcgcacca cctgcccggac    540
gctggtgttc acaactacga ccggtgcggc gcggccaacg agcgggagag gaggctgttc    600
cgcggcggcg acgagggcct cggcgcgcgc atggcgctcc acaccgccga cgtggcgacc    660
ctgacggggg agctcggcgc gtacgacgtc gtgttcctgg cggcgctcgt gggcatggcg    720
gccgaggaga aggcgggggt gatcgcgcac ctgggcccgc acatggcggg cggcgccggcg    780
ctcgtcgtgc ggacggcgca cggggcgcgc gggttcctgt acccgatcgt cgatcccag    840
gacgtcaggc gtggcggggt cgacgttctg gcggtgtgcc acccgaggga cgaggtgatc    900
aactccgtca tcgtgcccg caaggtcggg gccgcggccg ccgcccggcg ggcgcgcaga    960
gacgagctcg cggactcgcg cggcgtggtt ctgccggtgg tcgggcccgc gtccacgtgc   1020
tgcaaggtgg aggcgagcgc ggttgagaag gcagaagagt ttgccgcaa caaggagctg   1080
tccgtctaac agccggacga tcgaaaggcg cactatatta tggcaataaa tcatttgatt   1140
atacttatgc tgcatttgcg aagctaaggt atactatgca agccatatgt ttgtgttcgt   1200
acgtgttgtt tgggacgtac agttgtgttg ttgtacgtcg tgaagtactg aagtgttcac   1260
agtagatcac aagttcacag caatcaatga ggaccctgta agccagtgtg aacgaggaac   1320
atgccatctg tgtatgacag tgagaaatta tataagaaaa acattttgtg ac           1372

```

<210> SEQ ID NO 17

<211> LENGTH: 320

<212> TYPE: PRT

<213> ORGANISM: *Arabidopsis thaliana*

<400> SEQUENCE: 17

```

Met Ala Cys Gln Asn Asn Leu Val Val Lys Gln Ile Ile Asp Leu Tyr
  1             5             10             15
Asp Gln Ile Ser Lys Leu Lys Ser Leu Lys Pro Ser Lys Asn Val Asp
          20             25             30
Thr Leu Phe Gly Gln Leu Val Ser Thr Cys Leu Pro Thr Asp Thr Asn
          35             40             45
Ile Asp Val Thr Asn Met Cys Glu Glu Val Lys Asp Met Arg Ala Asn
          50             55             60
Leu Ile Lys Leu Cys Gly Glu Ala Glu Gly Tyr Leu Glu Gln His Phe
          65             70             75             80
Ser Thr Ile Leu Gly Ser Leu Gln Glu Asp Gln Asn Pro Leu Asp His
          85             90             95
Leu His Ile Phe Pro Tyr Tyr Ser Asn Tyr Leu Lys Leu Gly Lys Leu

```


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cacgcgatca tgaacaaccg tggtaagaag aatatgatcg aggagtttag taccatcgag 960
 taa 963

<210> SEQ ID NO 19
 <211> LENGTH: 320
 <212> TYPE: PRT
 <213> ORGANISM: Arabidopsis thaliana

<400> SEQUENCE: 19

Met Ala Cys Gln Asn Asn Leu Val Val Lys Gln Ile Met Asp Leu Tyr
 1 5 10 15
 Asn Gln Ile Ser Asn Leu Glu Ser Leu Lys Pro Ser Lys Asn Val Asp
 20 25 30
 Thr Leu Phe Arg Gln Leu Val Ser Thr Cys Leu Pro Thr Asp Thr Asn
 35 40 45
 Ile Asp Val Thr Glu Ile His Asp Glu Lys Val Lys Asp Met Arg Ser
 50 55 60
 His Leu Ile Lys Leu Cys Gly Glu Ala Glu Gly Tyr Leu Glu Gln His
 65 70 75 80
 Phe Ser Ala Ile Leu Gly Ser Phe Glu Asp Asn Pro Leu Asn His Leu
 85 90 95
 His Ile Phe Pro Tyr Tyr Asn Asn Tyr Leu Lys Leu Gly Lys Leu Glu
 100 105 110
 Phe Asp Leu Leu Ser Gln His Thr Thr His Val Pro Thr Lys Val Ala
 115 120 125
 Phe Ile Gly Ser Gly Pro Met Pro Leu Thr Ser Ile Val Leu Ala Lys
 130 135 140
 Phe His Leu Pro Asn Thr Thr Phe His Asn Phe Asp Ile Asp Ser His
 145 150 155 160
 Ala Asn Thr Leu Ala Ser Asn Leu Val Ser Arg Asp Ser Asp Leu Ser
 165 170 175
 Lys Arg Met Ile Phe His Thr Thr Asp Val Leu Asn Ala Lys Glu Gly
 180 185 190
 Leu Asp Gln Tyr Asp Val Val Phe Leu Ala Ala Leu Val Gly Met Asp
 195 200 205
 Lys Glu Ser Lys Val Lys Ala Ile Glu His Leu Glu Lys His Met Ala
 210 215 220
 Pro Gly Ala Val Val Met Leu Arg Ser Ala His Gly Leu Arg Ala Phe
 225 230 235 240
 Leu Tyr Pro Ile Val Asp Ser Cys Asp Leu Lys Gly Phe Glu Val Leu
 245 250 255
 Thr Ile Tyr His Pro Ser Asp Asp Val Val Asn Ser Val Val Ile Ala
 260 265 270
 Arg Lys Leu Gly Gly Ser Asn Gly Ala Arg Gly Ser Gln Ile Gly Arg
 275 280 285
 Cys Val Val Met Pro Cys Asn Cys Ser Lys Val His Ala Ile Leu Asn
 290 295 300
 Asn Arg Gly Met Glu Lys Asn Leu Ile Glu Glu Phe Ser Ala Ile Glu
 305 310 315 320

<210> SEQ ID NO 20
 <211> LENGTH: 963
 <212> TYPE: DNA
 <213> ORGANISM: Arabidopsis thaliana

<400> SEQUENCE: 20

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```

atggcttgcc aaaacaatct cgttggaag caaatcatgg acttatacaa ccaaattctca    60
aacctcgaga gcttaaaacc atccaagaat gtcgacactt tggtcagaca acttggtgcc    120
acgtgcttac caacggacac gaacatcgat gtcacagaga tacacgatga aaaagtcaaa    180
gacatgagat ctcatctcat caagctttgt ggtgaagccg aaggttattt agagcaacac    240
ttttcagcaa tcttaggctc ttttgaagac aacctctaa accatttaca catcttcccc    300
tattacaaca actatctcaa actaggcaaa ctgcaattcg atctcctttc tcagcacaca    360
acccatgtcc cgacaaaagt cgcttttatt ggttccggtc cgatgccact tacttccatc    420
gtcttgccca agttccacct ccccaacaca acgttcacaca acttcgacat cgactcacac    480
gccaacacac tcgcttcaaa cctcgtttct cgtgattctg acctttccaa acgcatgatt    540
ttccacacaa ctgatgtatt aaacgctaag gaggggtag accaatacga tgttgttttc    600
ttggcagctc ttgttgggat ggataaagag tcaaaggtaa aagctattga gcatttagag    660
aagcatatgg cccctggagc tgtggtgatg ctaagaagtg ctcatggtct tagagctttc    720
ttgtatccaa tcggtgactc ttgtgatctt aaagggtttg aggtgtaaac catttatcat    780
ccgctcgacg acgtggttaa ttcggtggtc atcgcacgta agcttggttg ttcaaatgga    840
gctcgaggca gccagatcgg acggtgtgtg gttatgcctt gtaattgctc taaggccac    900
gcgatcttga acaatcgtgg tatggagaag aatttgatcg aggagtttag tgccatcgag    960
taa                                                                 963

```

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<210> SEQ ID NO 21
<211> LENGTH: 320
<212> TYPE: PRT
<213> ORGANISM: Arabidopsis thaliana

```

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<400> SEQUENCE: 21

```

```

Met Gly Cys Gln Asp Glu Gln Leu Val Gln Thr Ile Cys Asp Leu Tyr
 1           5           10           15
Glu Lys Ile Ser Lys Leu Glu Ser Leu Lys Pro Ser Glu Asp Val Asn
 20           25           30
Ile Leu Phe Lys Gln Leu Val Ser Thr Cys Ile Pro Pro Asn Pro Asn
 35           40           45
Ile Asp Val Thr Lys Met Cys Asp Arg Val Gln Glu Ile Arg Leu Asn
 50           55           60
Leu Ile Lys Ile Cys Gly Leu Ala Glu Gly His Leu Glu Asn His Phe
 65           70           75           80
Ser Ser Ile Leu Thr Ser Tyr Gln Asp Asn Pro Leu His His Leu Asn
 85           90           95
Ile Phe Pro Tyr Tyr Asn Asn Tyr Leu Lys Leu Gly Lys Leu Glu Phe
100          105          110
Asp Leu Leu Glu Gln Asn Leu Asn Gly Phe Val Pro Lys Ser Val Ala
115          120          125
Phe Ile Gly Ser Gly Pro Leu Pro Leu Thr Ser Ile Val Leu Ala Ser
130          135          140
Phe His Leu Lys Asp Thr Ile Phe His Asn Phe Asp Ile Asp Pro Ser
145          150          155          160
Ala Asn Ser Leu Ala Ser Leu Leu Val Ser Ser Asp Pro Asp Ile Ser
165          170          175
Gln Arg Met Phe Phe His Thr Val Asp Ile Met Asp Val Thr Glu Ser
180          185          190

```

-continued

Leu	Lys	Ser	Phe	Asp	Val	Val	Phe	Leu	Ala	Ala	Leu	Val	Gly	Met	Asn
	195						200					205			
Lys	Glu	Glu	Lys	Val	Lys	Val	Ile	Glu	His	Leu	Gln	Lys	His	Met	Ala
	210					215					220				
Pro	Gly	Ala	Val	Leu	Met	Leu	Arg	Ser	Ala	His	Gly	Pro	Arg	Ala	Phe
225					230					235					240
Leu	Tyr	Pro	Ile	Val	Glu	Pro	Cys	Asp	Leu	Gln	Gly	Phe	Glu	Val	Leu
				245					250					255	
Ser	Ile	Tyr	His	Pro	Thr	Asp	Asp	Val	Ile	Asn	Ser	Val	Val	Ile	Ser
			260					265					270		
Lys	Lys	His	Pro	Val	Val	Ser	Ile	Gly	Asn	Val	Gly	Gly	Pro	Asn	Ser
		275					280					285			
Cys	Leu	Leu	Lys	Pro	Cys	Asn	Cys	Ser	Lys	Thr	His	Ala	Lys	Met	Asn
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<210> SEQ ID NO 22

<211> LENGTH: 963

<212> TYPE: DNA

<213> ORGANISM: Arabidopsis thaliana

<400> SEQUENCE: 22

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gcgaaaatga acaagaacat gatgatcgag gagttcggag ctagggagga acagttgtct    960
taa

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The invention claimed is:

1. An isolated nucleic acid molecule encoding a nicotianamine synthase polypeptide that is at least 90% identical to SEQ ID NO: 1.

2. The isolated nucleic acid of claim 1, wherein the amino acid sequence is at least 95% to SEQ ID NO: 1.

3. An isolated nucleic acid molecule consisting of the nucleic acid sequence set forth as SEQ ID NO:2.

4. The nucleic acid molecule of claim 1, wherein the nucleic acid molecule encodes a polypeptide comprising at least one of the consensus sequences of SEQ ID NO: 1 wherein the consensus sequence is selected from the group consisting of:

- (1) ²⁵LPXLSPSPXVDRLF⁵⁶TXLVXACVPXPSPVD-VTKL⁵⁶ (SEQ ID NO: 23)
- (2) ⁶⁷LIRLCSXAEGXLEAHY⁸² (SEQ ID NO: 24)
- (3) ⁹²PLDHLGXFPY¹⁰¹ (SEQ ID NO: 25)

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- (4) ₁₂₈ VAFXGSGPLPFSS₁₄₀ (SEQ ID NO: 26)
- (5) ₁₉₉ DVVFLAALVGM₂₀₉ (SEQ ID NO: 27) and
- (6) ₂₅₃ RGGFXVLAVXHP₂₆₄ (SEQ ID NO: 28).
- 5.** A vector comprising the nucleic acid molecule set forth in any one of claims **1-4**.
- 6.** An isolated host cell comprising the vector of claim **5**.

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- 7.** The isolated host cell of claim **6**, wherein the host cell is a plant cell.
- 8.** The isolated host cell of claim **6**, wherein the host cell is a bacterial cell.

* * * * *